INJURY-FREE RUNNING – A UTOPIA?

Risk Factors of Running-Related Injuries in Men and Women

Maarten van der Worp

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Contents

Chapter 1

General Introduction

General Introduction

For centuries, it has been recognized that physical activity and physical fitness promote health and longevity. The consensus statement from an evidence-based symposium[1] concluded that a large body of evidence supports the contention that physical activity produces a number of major health benefits. Regular physical activity is associated with a reduction in all-cause mortality, fatal and nonfatal cardiovascular disease, and coronary heart disease. It is also associated with a reduction in the incidence of obesity, type 2 diabetes mellitus, blood pressure, colon cancer, and osteoporosis. Further benefits of regular physical activity include improved physical functioning and independent living in the elderly. Physically active individuals are less likely to develop depressive illness than their more sedentary counterparts. Moreover, in people with mild-to-moderate depression and anxiety, physical activity is associated with an improvement in symptoms[1].

In 2010, the British Association of Sports and Exercise published the ABC of physical activity for health[2], evidence-based recommendations for the minimum amount of activity associated with health and wellbeing. For example, healthy adults aged 18–65 years should aim to take part in at least 150 min of moderate-intensive aerobic activity a week, or at least 75 min of vigorous-intensive aerobic activity a week, or equivalent combinations of moderate- and vigorous-intensive aerobic activities. Moderate-intensive activities are those in which heart rate and breathing are raised, but it is possible to speak comfortably. Vigorous-intensive activities are aerobic exercises in which the heart rate is higher, breathing is heavier, and fluent conversation is more difficult. Aerobic activities should be undertaken in bouts of at least 10 min and, ideally, should be performed 5 or more days a week[2].

Although many sports provide the aerobic activity goals recommended in "the ABC of physical activity for health[2]", running seems to be ideal – it can be done almost anywhere, alone or in a group, at any desired time, and expensive equipment is not needed as simple sportswear and running shoes are sufficient.

Running is one of the most popular physical activities among adults worldwide, and in many Western countries cities have their own recreational running events. More than 35 million people in the United States run for exercise or sport, with a wide spectrum of running exposure[3]. Running is also very popular in the Netherlands (population 16.8 million). In 2012, about 12 million Dutch inhabitants participated in some form of sport[4], of which about 1.9 million in running[5]. After fitness, running is the second most popular sport in this country[6].

In the 1970s, the pioneers of running were mainly upper class white men, often former track and field athletes with a background in running, who increasingly often participated in the annual marathons of Boston, New York, and other running events[7 8]. These runners had an active lifestyle and a toned physique, which was considered prestigious and attracted admiration and respect across a broad social spectrum. This changed running into a sport with status, and its popularity spread rapidly across the American continent[8]. Running changed from an 'elite' sport into one that was accessible to all, with runners participating for social and physical reasons[7 8].

The second explosive growth in the number of active runners occurred in the late

1990s, for four main reasons: (1) increased importance given to physicality (slim, muscular), fitness, and health; (2) this was especially the case among women; (3) increased opportunities to run in a way that is compatible with the goals of weight management, muscularity, fitness, and health; and (4) lower barriers to participation in running and running events as a result of professionalization and commercialization of opportunities[7].

In the Netherlands, the third explosive growth in the number of new runners occurred in 2012. While the number of runners in the Netherlands was stable in the period 2006–2011, in 2012 there was a significant increase of 450,000 runners in 1 years' time, with about 13% of the Dutch population being active runners[9]. This significant increase was probably due to an increase in the number of women who started running and an increase in the number of runners participating in specific running events[10 11].

In conclusion, running is very popular, the number of runners is still growing, and the people who run, run more often[5]. Because running has a low threshold, it is an ideal aerobic activity for health and wellbeing[1], for both preventive (e.g. heart disease and obesity[2]) and intervention (e.g. improvement in the metabolic control of individuals with established type 2 diabetes and reduction in blood pressure[1]) purposes.

Running-Related Injury (RRI)

A major drawback of running is the relatively high risk of injury. Injuries diminish pleasure in exercise and lead to a temporary or even permanent discontinuation of running, with the subsequent loss of the beneficial effects on health and wellbeing. Moreover, injuries increase costs because of necessary medical treatment.

Depending on the definition of RRI used, the type of runner investigated, the follow-up time of the study, and the study design, injury incidence rates varying between 20% and 79% have been reported[12]. Running is one of the most common sports that gives rise to overuse injuries of the lower back and leg[13]. In the Netherlands, with a running population of 1.9 million, 610,000 people suffered from an RRI in 2012. This translates into 5.6 RRIs per 1000 running hours, a relatively high rate (mean injury of 2.0 per 1000 sport hours). After indoor soccer and hockey, running is the sport with the highest prevalence of injury in the Netherlands[5].

The predominant site of RRIs is the knee, with an injury incidence rate of 7.2% to 50.0%[12]. For example, iliotibial band syndrome (ITBS) is estimated to have a prevalence of between 16% and 50% among women[14-19] and between 50% and 81% among men,[14-17 19]making it is the most common running injury of the lateral side of the knee[20].

In a survey of sports injuries held in the Netherlands in 2012, over a third (31%; 190,000) of injured runners sought medical treatment[5]. Most of these runners were treated by a physical therapist, with a total number of 600,000 treatments[5] and an estimated cost of €21 million per year. In some instances, runners had to go to the emergency department of a hospital. In total, 2100 people visited an emergency department for an injury sustained during running. These runners accounted for only 1% of all sports injuries treated in an emergency department in 2012 in the Netherlands[5]. The direct medical costs per injured runner treated in the emergency department were estimated at €1300, with a total of €2.9 million[5]. Of course, the direct costs depend on the type of injury. On average, musculoskeletal injuries were significantly more expensive (€1100) than superficial injuries (€700) and distortions (€800)[5]. In 2012, the cost of work absenteeism for runners who were treated for an RRI at an emergency department was on average €5400 per RRI, with a total of €5.4 million[5]. The average cost of absenteeism because of an RRI that was treated at an emergency department or required hospitalization was slightly lower than that of absenteeism because of general sports injury. Again, the cost of absenteeism depended on the type of injury[5]. In conclusion, the rate of running injuries and the costs of treatment and absenteeism are relatively high, especially for knee injuries.

Etiology of RRIs

There are basically two types of injuries: acute injuries and overuse injuries. Acute injuries are usually the result of a single, traumatic event (macro-trauma). Acute running injuries are rare, consisting mainly of muscle injuries, sprain, or skin lesions (blisters and abrasions)[21]. Overuse injuries are more subtle and usually develop over time. In running, overuse injuries of the musculoskeletal system generally occur when a structure is exposed to repetitive forces, each below the acute threshold of a structure, but producing a combined fatigue effect over time that is beyond the capabilities of the specific structure[22]. With running, bones, muscles, tendons, and ligaments become stronger and more functional as a result of remodeling. This process is also involved in damage repair, and if there is enough time for adaptation, the musculoskeletal system gets stronger and better able to withstand the loads to which it is exposed[13].

Running injuries have a multifactorial origin that can be subdivided into personal (e.g., age, weight, etc.), running/training (e.g., weekly trainings frequency, running surface), and health and/or lifestyle factors (e.g., other sports activity's, history of injury, etc.) [23-25]. These factors interacting with each other and their influence may also be mediated by cultural or societal factors[26]. The importance of each factor, and hence its contribution to the risk of symptoms and injuries, varies among individuals and running environments[27]. Moreover, the exact causes of running injuries are likely to be diverse[12].

A theoretical model for the etiology of running injuries should be based on risk factors identified in the literature, prospective studies, and/or on a rational theory supported by scientific evidence. The identification of risk factors may contribute to the development of injury prevention strategies and/or screening possibilities, especially when risk factors can be modified by adequate training, by optimizing the training environment, and by using orthotics or modified footwear.

Reproducibility

To identify risk factors for RRI in prospective studies, it is important to use reliable instruments with a high reproducibility[28]. Reliability and agreement are population specific and protocol dependent, respectively[28]. A false impression of the reproducibility of an instrument may be gained if it is used in other populations or with a different measurement protocol than when its clinimetric properties were established. For this reason, prior to prospective cohort studies involving runners, clinimetric studies should be performed involving similar types of runners and using the same measurement protocol.

Sex Differences

In the last 35 years, the participation of women in sports has increased significantly in the United States, possibly after the introduction of legislation against sex discrimination in education and programs that receive federal funding[29]. The proportion of female and male runners in the Netherlands is 41% and 59%, respectively.

The risk factors for RRIs differ between male and female athletes, possibly due to differences in anatomy (e.g., females have shorter and smaller limbs relative to body size and have a greater general mobility[30]), physiology (e.g., females have a lower diastolic and systolic blood pressure)[31 32] and different pain mechanisms[33].

However, little is known about predictors of RRIs in female runners in particular, and a better knowledge of these predictors in this group would enable targeted prevention strategies, which is especially interesting given the growing group of female "event" runners[34].

Conclusion

In conclusion, running is very popular worldwide and has a positive effect on general health and wellbeing. Furthermore, this aerobic sport is effective in both curative and preventive settings[2]. However, the rate of RRI and the additional costs are high, especially for knee injuries[5 12]. In addition, the risk profile of female and male runners may be different, but this has not yet been established firmly. In particular, female runners are particularly interesting because running is still a growth sport among women, and a better knowledge of risk factors for RRIs in female runners would enable targeted prevention strategies.

Outline of the thesis

Chapter 2 describes a systematic literature review that investigated the quality of scientific knowledge of the iliotibial band syndrome (ITBS). ITBS, the runners knee, is the most frequent RRI on the lateral side of the knee and is caused due irritation of the iliotibial band on the lateral epi-condyle of the femur. The study described in chapter 3 investigates, by means of a review of current evidence, risk factors for RRIs in adults and whether risk factors for these injuries differ in female and male runners. The study reported in chapter 4 describes the findings of a study assessing the reliability of three orthopedic tests (the navicular drop-test, the ankle joint dorsiflexion-test, and the extension MTP1-test) that are often used in daily running practice to identify runners at higher RRI risk. Finally, chapter 5 and chapter 6 describe studies involving women who participated in the women-only Marikenloop run. The incidence, characteristics, and specific predictors of RRI among female runners training for a 5- or 10-km race are described in chapter 5, and nutritional indicators of gastrointestinal symptoms in female runners are described in chapter 6. The general discussion is presented in chapter 7 and the thesis ends with a summary in English and Dutch, respectively chapter 8 and chapter 9.

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Chapter 2

ILIOTIBIAL BAND SYNDROME IN RUNNERS: A SYSTEMATIC REVIEW

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Abstract

Background: The popularity of running is still growing and, as participation increases, the incidence of running-related injuries will also rise. Iliotibial band syndrome (ITBS) is the most common injury of the lateral side of the knee in runners, with an incidence estimated to be between 5% and 14%. In order to facilitate the evidence-based management of ITBS in runners, more needs to be learned about the aetiology, diagnosis and treatment of this injury.

Objective: This article provides a systematic review of the literature on the aetiology, diagnosis and treatment of ITBS in runners.

Search strategy: The Cochrane Library, MEDLINE, EMBASE, CINAHL, Web of Science, and reference lists were searched for relevant articles.

Selection criteria: Systematic reviews, clinical trials or observational studies involving adult runners (>18 years) that focused on the aetiology, diagnosis and/or treatment of ITBS were included and articles not written in English, French, German or Dutch were excluded.

Data collection and analysis: Two reviewers independently screened search results, assessed methodological quality and extracted data. The sum of all positive ratings divided by the maximum score was the percentage quality score (QS). Only studies with a QS higher than 60% were included in the analysis. The following data were extracted: study design; number and characteristics of participants; diagnostic criteria for ITBS; exposure/treatment characteristics; analyses/outcome variables of the study; and setting and theoretical perspective on ITBS.

Main results: The studies of the aetiology of ITBS in runners provide limited or conflicting evidence and it is not clear whether hip abductor weakness has a major role in ITBS. The kinetics and kinematics of the hip, knee and/or ankle/foot appear to be considerably different in runners with ITBS to those without. The biomechanical studies involved small samples, and data seem to have been influenced by sex, height and weight of participants. Although most studies monitored the management of ITBS using clinical tests, these tests have not been validated for this patient group. While the articles were inconsistent regarding the treatment of ITBS, hip/knee coordination and running style appear to be key factors in the treatment of ITBS. Runners might also benefit from mobilization, exercises to strengthen the hip, and advice about running shoes and running surface.

Conclusion: The methodological quality of research into the management of ITBS in runners is poor and the results are highly conflicting. Therefore, the study designs should be improved to prevent selection bias and to increase the generalizability of findings.

Background

In the last 30 years, running has become popular worldwide.[1] The Royal Dutch Athletics Federation (KNAU) has estimated that about 12.5% of the Dutch population runs regularly, and that the popularity of running events is still growing.[2]

Running is an inexpensive form of vigorous-intensive physical activity and can be done anywhere and at any time;[1] it is also a basic aspect of many recreational and professional sports. However, running may cause overuse injuries, especially in the legs.[3] Various studies have reported on the prevalence and incidence of running injuries occurring during training or races,[3] with injury rates varying between 25% and 65%,[4] although a rate of about 51% has been reported in college athletes and between 20% and 50% in soldiers.[5,6] Iliotibial band syndrome (ITBS) is the most common running injury of the lateral side of the knee.[7] It is a non-traumatic overuse injurycaused by repeated flexion and extension of the knee that causes irritation in the structures around the knee.[8-11] Orchard et al.[12] described an 'impingement zone' occurring at, or slightly below, 30° of knee flexion during foot strike and the early stance phase of running. During this impingement period in the running cycle, eccentric contraction of the tensor fascia latae muscle and of the gluteus maximus muscle causes the leg to decelerate, generating tension in the iliotibial band.[12,13] ITBS is usually diagnosed on the basis of a detailed history and physical examination.[14] It was first initially described by Colson and Armour,[15] and later by Renne,[8] as pain in the lateral side of the knee during running. The incidence of ITBS by runners is estimated to be between 5% and 14%[11,16-21] depending on the differences in study design, sample size and running population; weekly running time/distance, level of performance and sex. In the ITBS population the prevalence of women is estimated to be between 16% and 50%[11,17,19-22] and for men between 50% and 81%.[11,17,19-21] However, it is still difficult to establish the incidence of ITBS in runners because many studies do not specifically report the incidence of ITBS and the characteristics of this group but, instead, report the incidence of all knee injuries.[13] The aetiology of ITBS is mostly multifactorial, involving both intrinsic and extrinsic factors.[23]

Several authors have reported that ITBS responds well to conservative and surgical treatment.[11,13,24-28] This study aims to systematically review the literature on ITBS to gain insight into the aetiology, diagnosis and treatment of ITBS in runners, in order to promote evidence-based management.

Methods

Literature Search

We performed a computerized search of bibliographical databases, including MEDLINE (from 1966 to December 2011), EMBASE (from 1980 to December 2011), CINAHL (from 1982 to December 2011), Web of Science (from 1988 to December 2011) and the Cochrane Library (from 2009 to December 2011) using the following search terms: 'iliotibial band friction syndrome', 'iliotibial band syndrome' and 'iliotibial band strain'all in combination with running and with no restriction for language. The first author (MvdW) screened titles and abstracts of all identified citations to identify relevant studies and searched the reference lists of the retrieved articles to identify other potential studies. Two independent reviewers (MvdW and NvdH) screened the retrieved articles, using the following inclusion criteria: studies that investigated the aetiology, diagnostics and/or treatment of ITBS; study subjects who were adult runners (aged >18 years); study designs that were systematic reviews, (randomized) clinical trials or observational studies (longitudinal, cross sectional or case referent), and studies reported in English, French, German or Dutch. Differences in article selection between the two reviewers were resolved in a consensus meeting. If consensus was not reached, a third reviewer (AW) made the final decision for inclusion or exclusion of the article.

Methodological Quality

The methodological quality of the articles was assessed by two independent reviewers (NvdH and MvdW), using appropriate Cochrane Collaboration criteria.[29] Criteria not applicable for a given design were not taken into account. This resulted in nine items being scored for randomized clinical trials, eight for cohort analyses, and six for case referent and cross-sectional studies. Scoring of the different study types were as follows:

- Randomized clinical trials:
  (i) subjects were randomly allocated to groups;
  (ii) allocation was concealed;
  (iii) there was blinding of all subjects/patients;
  (iv) there was blinding for all care providers;
  (v) there was blinding of all assessors who measured at least one key outcome;
  (vi) groups were similar at baseline; (vii) followup assessment is of sufficient length;
  (viii) study included an intent-to-treat analysis; and
  (ix) all groups, except those in the intervention group, were treated similarly.[29]
- Observational studies: (i) description of the main characteristics of the study population or cases; (ii) description of the main characteristics of the referents; (iii) exclusion of selection bias; (iv) description and measurement of exposure; (v) description and measurement of the outcome variable; (vi) blinding of the measurement outcome variable; (vii) follow-up assessment is of sufficient length; (viii) exclusion selective loss to follow-up; (ix) inclusion of confounding variables in statistical analysis.[29]

For each study, a quality score (QS) was calculated by summing the positive ratings and dividing this by the maximum score for that type of study. The methodological QS was judged adequate if the score was more than 60%. Differences in the assessment of methodological quality were settled in a consensus meeting and, if necessary, by a third reviewer (AW). The rate of agreement about the quality of studies was then calculated.

The level of scientific evidence regarding ITBS was as follows:[30]
- level I, strong evidence provided by systematic reviews;
- level II, moderate evidence provided by generally consistent findings in multiple adequate quality studies (QS >60%);
- level III, limited evidence provided by one highquality study or by generally consistent findings in multiple low-quality studies;
- level IV, conflicting evidence in case of inconsistent findings;
- level V, no evidence, expert based.

Data Extraction and Analysis
Only studies with a QS higher than 60% were included in the analysis. The following information was extracted from articles providing level I–IV evidence: study design; population characteristics; number of participants; how ITBS was diagnosed; exposure/treatment characteristics; analyses/outcome variables of the study; and setting and the theoretical perspective of ITBS.

Results
Literature Search
A flow chart for article retrieval is given in figure 1. Of 209 articles retrieved as potentially relevant, 108 were considered eligible for full-text screening, and 36 of these met the inclusion criteria. Articles that failed to meet inclusion criteria were narrative reviews,[9,23-28,31-48] casuistic cases,[49-59] case reports[60-62] and a commentary.[63] Thirteen studies did not involve runners,[5,7,8,64-73] 18 did not investigate ITBS[14,20,74-88] and one was written in Serbian.[89]

Methodological Quality
The 36 included studies are ranked by QS and subsequently in alphabetic order of first author's name in table I. Initially, both reviewers agreed about 151 (60%) of the 232 items. All disagreements were resolved during one consensus meeting. Fourteen (11 observational and 3 randomized clinical trials) studies fulfilled the methodological quality criteria (QS >60%) and provided level I–IV evidence according to the CEBM (Centre of Evidence Based Medicine).[30] The three randomized clinical trials met requirements regarding randomization, baseline similarity of groups, length of follow-up and similarity of treatment (except the intervention) between groups. However, treatment allocation was not concealed (or reported) in these three studies and it could not be ascertained from the information provided whether the outcome assessor was blinded in the study of Gunter and Schwellnus.[91] All observational studies met the requirements regarding the description of the population/cases and, where appropriate, the length of follow-up.

Data Extraction and Analysis
The 14 studies investigated factors contributing to ITBS in runners [16,17,22,93-97] its diagnosis, if it was based on history, physical examination complemented by clinical findings and supplementary tests,[90-92,94,96-98] and treatment.[16,90-92,97-99] One study[100] established normative data for the Ober and modified Thomas tests. All these studies are summarized in tables II–IV, respectively, in alphabetic order of first author's name.

Aetiology
Three main factors were investigated with regard to the aetiology of IBTS: the strength of the hip abductors, biomechanics and the choice of shoe and running surface.

Strength of the Hip Abductors
Grau et al.[9 3]measured the isometric, concentric and eccentric peak torque of the hip abductors/ adductors at 30/s and calculated the concentric endurance quotient at 30/s. They found no difference between runners with (n = 10) or without ITBS (n = 10), matched by age, sex, weight and weekly running distance (at least 20 km).[93] Fredericson et al.[97] compared the pre-rehabilitation hip abductor torque (measured with a hand-held dynamometer; break method) between the injured and uninjured side in runners with and without ITBS. The ITBS group for this study consisted of 24 consecutive collegiate and club long-distance runners who presented to the Runners' Injury Clinic for initial evaluation and were diagnosed with ITBS. The mean age and weight of this group was 27.6 years (95% CI 3.66) and 58.73 kg (95% CI 4.02) for women (n = 10), and 27.07 years (95% CI 4) and 71.85 kg (95% CI 2.69) for men (n = 10), respectively. The control group of 30 distance runners (14 female, 16 male) subjects were all Stanford University cross-country and track runners, who were randomly selected to participate in this study during their pre-season physicals. They found in this larger and homogeneous group that the pre-rehabilitation hip abductor torque was significantly lower on the injured side in male and female runners with ITBS than in runners without ITBS.[97]

Biomechanics
In another study, Grau et al.[94] investigated biomechanical (kinematic and kinetic) differences between runners with and without ITBS, using control groups of healthy runners: control group (CG) I (n = 18) unmatched, CG II (n = 18) matched for sex, and CG III (n = 18) matched for sex, height and weight. All subjects ran barefoot along a 13m ethylene vinyl acetate (EVA) foam

Table I. Methodological quality assessment of the randomized controlled trials and the observational studies with their quality score

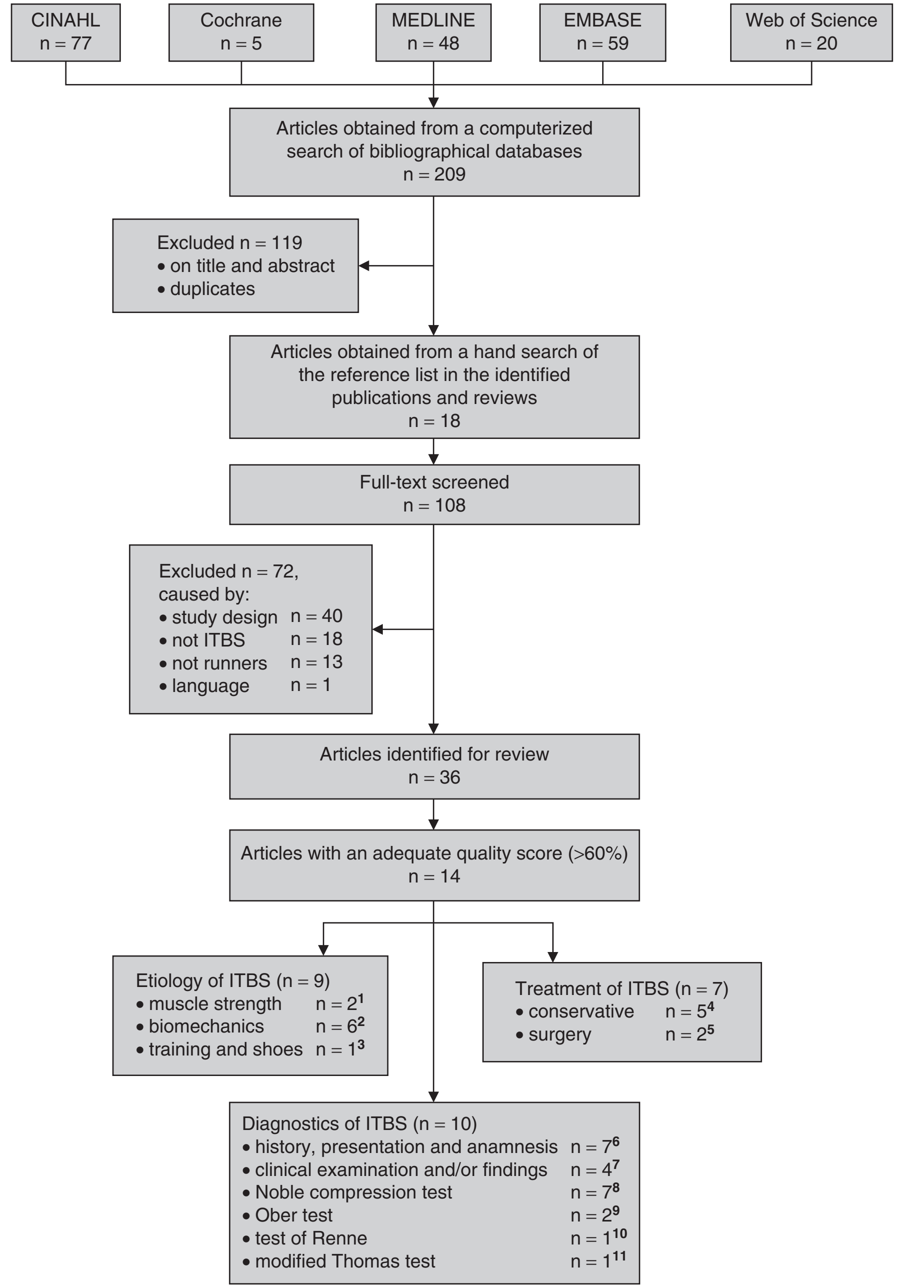
Study (y)	Scoring items										
	1[a,b]	2[a,b]	3[a,b]	4[a,b]	5[a,b]	6[a,b]	7[a,b]	8[a,b]	9[a,b]	Total scores[c]	QS
RCTs											
Schwellnus et al.[90] (1991)	+	–	+	+	+	+	+	–	+	7	78
Gunter and Schwellnus[91] (2004)	+	–	+	–	–	+	+	+	+	6	67
Schwellnus et al.[92] (1992)	+	–	–	–	+	+	+	+	+	6	67
Observational studies											
Grau et al.[93] (2008)	+	+	+	+	NA	NR	NA	NA	+	5	100
Grau et al.[94] (2008)	+	+	+	+	NA	NR	NA	NA	+	5	100
Noehren et al.[22] (2007)	+	+	+	+	NA	NR	NA	NA	+	5	100
Taunton et al.[17] (2002)	+	NA	+	+	+	NR	NA	NA	+	5	100
Ferber et al.[95] (2010)	+	+	–	+	NA	NR	NA	NA	+	4	80
Grau et al.[96] (2011)	+	+	+	–	NA	NR	NA	NA	+	4	80
Fredericson et al.[97] (2000)	+	NA	+	–	–	NR	+	+	+	5	71
Hariri et al.[98] (2009)	+	NA	–	+	+	NR	+	+	–	5	71
Michels et al.[99] (2009)	+	NA	+	+	–	NR	+	+	–	5	71
Pinshaw et al.[16] (1984)	+	NA	–	+	+	NR	+	–	+	5	71
Ferber et al.[100] (2010)	+	NA	–	+	+	–	NA	NA	+	4	67
Fredericson et al.[101] (2002)	–	NA	–	+	+	NR	NA	NA	+	3	60
Hein et al.[102] (2011)	+	+	–	+	NA	NR	NA	NA	–	3	60
Miller et al.[103] (2008)	+	+	–	+	NA	NR	NA	NA	–	3	60
Drogset et al.[104] (1999)	–	NA	–	+	–	NR	+	+	–	3	43
Lindenberg et al.[105] (1984)	–	NA	–	+	–	NR	+	+	–	3	43
McNicol et al.[11] (1981)	+	NA	–	–	–	NR	+	–	+	3	43
Sutker et al.[21] (1985)	–	NA	–	+	–	NR	+	+	–	3	43
Messier et al.[19] (1995)	–	–	–	+	NA	NR	NA	NA	+	2	40
Nishimura et al.[106] (1997)	+	–	–	+	NA	NR	NA	NA	–	2	40
Barber and Sutker[107] (2008)	–	NA	–	+	–	NR	+	–	–	2	29
Beers et al.[108] (2008)	–	NA	–	–	+	NR	–	+	–	2	29
Noble[109] (1979)	–	NA	–	+	–	NR	+	–	–	2	29
Noble[110] (1980)	–	NA	–	+	–	NR	–	–	+	2	29
Hamill et al.[111] (2008)	–	–	–	+	NA	NR	NA	NA	–	1	20
Messier and Pittala[112] (1988)	–	–	–	+	NA	NR	NA	NA	–	1	20
Miller et al.[113] (2007)	–	–	–	+	NA	NR	NA	NA	–	1	20
Orchard et al.[12] (1996)	–	NA	–	+	–	NR	NA	NA	–	1	20
Barber and Sutker[114] (1992)	–	NA	–	–	–	NR	–	+	–	1	14
Martens et al.[115] (1989)	–	NA	–	+	–	NR	–	–	–	1	14
Nillson and Staff[116] (1973)	–	NA	–	–	–	NR	–	+	–	1	14
Nemeth and Sanders[10] (1996)	–	NA	–	–	–	NR	–	–	–	0	0
Noehren et al.[117] (2006)	–	–	–	–	NA	NR	NA	NA	–	0	0

a Scoring items – RCT: 1 = randomization; 2 = treatment allocation concealed; 3 = patient blinded; 4 = care-provider blinded; 5 = outcome assessor blinded; 6 = groups similar at baseline; 7 = follow-up of sufficient length; 8 = included an intent-to-treat analysis; 9 = all groups, except intervention, treated similarly.

b Scoring items – observational studies: 1 = description population/cases; 2 = description referents; 3 = exclusion selection bias; 4 = description and measurement exposure; 5 = description and measurement outcome variable; 6 = blinding measurement outcome variable; 7 = follow-up of sufficient length; 8 = exclusion selective loss to follow-up; 9 = inclusion confounding variables.

c Total score from both RCT and observational studies.

NA = not applicable; **NR** = not relevant; **QS** = quality score; **RCTs** = randomized controlled trials; + indicates yes; – indicates no.



1 = [93,97] **5** = [98,99] **9** = [96,100]
2 = [16,17,22,94,96,95] **6** = [90-92,94,96-98] **10** = [91]
3 = [16] **7** = [91,94,97,99] **11** = [100]
4 = [16,90-92,97] **8** = [16,90-92,96-98]

Fig. 1. Flow chart of the search of scientific publications and the studies with an adequate quality scores in the management of iliotibial band syndrome. ITBS = iliotibial band syndrome.

Table II. Observational studies: aetiology of iliotibial band syndrome in runners

Study (y)	Design	Population[a]	Follow up	Diagnostic ITBS	Exposure/treatment	Analyses/outcome[b]	Setting	Theoretical perspective
Ferber et al.[95] (2010)	Case referent	N = 400; 100% F; runners, minimum 30 km/wk; aged between 18 and 45 y: ITBS group in the past - N = 35; all F - Age 35.47 ± 10.35 y - Height 1.65 ± 0.06 m - Weight 58.62 ± 3.97 kg - MRD 123.82 ± 62.64 km CG: - N = 35; 100% F - Age 31.23 ± 11.05 y - Height 1.67 ± 0.07 m - Weight 61.30 ± 6.97 kg - MRD 119.27 ± 52.02 km	NA	NF	All subjects ran along 25 m runway - Speed; 3.65 m/s - Data from 5 trails were averaged: • Foot Peak RFEA, RFIM • Knee Peak knee IR angle, peak knee ERM, peak KF angle • Hip Peak (HADD), peak HABM	Foot (ITBS vs CG) - RFEV: 8.94 ± 3.16° vs 10.04 ± 3.22°; p = 0.36 - RFIM: 014 ± 0.13 Nm/kg vs 0.09 ± 0.08 Nm/kg; p = 0.05 Knee (ITBS vs CG) - IR: 1.75 ± 5.94° vs –1.14 ± 4.94°; p = 0.03 - ERM: 0.09 ± 0.06 Nm/kg vs 0.09 ± 0.05; Nm/kg p = 0.68 - KF; 45.30 ± 4.50° vs 45.21 ± 5.00°; p = 0.95 Hip (ITBS vs CG) - HADD: 10.39 ± 4.36° vs 7.92 ± 5.84°; p = 0.05 - HABM; 15.33 ± 0.24 Nm/kg vs 1.33 ± 0.18 Nm/kg; p = 0.94	NF (lab?)	NF
Fredericson et al.[97] (2000)	Cohort: longitudinal prospective	N = 54; 26 M, 28 F; ITBS group: - N = 24; 10 M, 14 F; distance runners; M: - Age 27.07 y (95% CI 4.0) - Height 1.78 m (95% CI 0.03) - Weight 71.85 kg (95% CI 2.69) F: - Age 27.6 y (95% CI 3.66) - Height 1.67 m (95% CI 0.06) - Weight 58.73 kg (95% CI 4.02) CG: - N = 30, 16 M, 14 F distance runners; cross-country and track team	6 wk	History, presentation, clinical examination and Noble compression test	ITBS group: 6 wk standardized rehabilitation programme: - No running at the beginning - Once a wk physical therapy; • Ultrasound with corticosteroid gel, etc. - NSAIDs until pain free with daily activities - Stretch exercises for iliotibial band (3 × day) - Hip abd exercises and pelvic drop exercise 5 sets of 30 reps	Pre-rehab. hip abd torque M: - ITBS: 6.86 ± 1.19% injured leg - ITBS: 8.62 ± 1.16% non-injured leg - CG: 9.73 ± 1.3% F: - ITBS: 7.82 ± 1.93% injured leg - ITBS: 9.82 ± 2.987% non-injured leg - CG: 10.19 ± 1.10% All groups differed significantly p ≤ 0.05 Post-rehab. hip abd torque - ITBS: M 51% increase - ITBS: F 34.9% increase After 6 wk 22 athletes pain free and running. After 6 mo no reports of recurrence	Stanford University Sports Medicine Clinics, California, USA	Biomedical; iliotibial band

Continued next page

Table II. Contd

Study (y)	Design	Population[a]	Follow up	Diagnostic ITBS	Exposure/treatment	Analyses/outcome[b]	Setting	Theoretical perspective
Grau et al.[93] (2008)	Case Referent	N = 20; 14 M, 6 F; ITBS group: - N = 10; 7 M, 3 F - Age 41 ± 7 y - Height 178 ± 8 cm - Weight 69 ± 9 kg - Weekly running >20 km CG: - N = 10; 7 M, 3 F; healthy runners - Age 38 ± 6 y - Height 179 ± 8 cm - Weight 70 ± 98 kg - Weekly running >20 km	NA	NF	Isokinetic measurement (30°/s) - Isometric hip abd/add - Concentric hip abd/add - Eccentric hip abd/add - Endurance (concentric) • 20 reps at 30°/s, 3 max. of the last 5 contractions divided by 3 max. of the first 5 contractions	No significant difference between the CG and the ITBS group for isometric, concentric, eccentric and the endurance contractions. No significant difference between the injured and non-injured side ITBS group for isometric, concentric, eccentric and the endurance contractions	Department of Sports Medicine, Medical Clinic University of Tübingen, Tübingen Germany	Biomedical; iliotibial band
Grau et al.[94] (2008)	Case referent	N = 70; runners ITBS group: - N = 18; 13 M, 5 F - Age 35.7 ± 6.8 y - Height 177 ± 8.6 cm - Weight 71 ± 11.6 kg - BMI 22 ± 2.6 kg/m^2 CG I healthy runners: - N = 18; 11 M, 7 F - Age 36.6 ± 6.7 y - Height 172 ± 8 cm - Weight 65 ± 11.6 kg - BMI 22 ± 2.2 kg/m^2 CG II sex-matched healthy runners: - N = 18; 13 M, 5 F - Age 41.8 ± 6.5 y - Height 173 ± 7.8 cm - Weight 66 ± 9,8 kg - BMI 22 ± 2.0 kg/m^2 CG III sex/age/height/weight-matched healthy runners: - N = 18; 13 M, 5 F - Age 41.8 ± 6.5 y - Height 173 ± 7.8 cm - Weight 66 ± 9.8 kg - BMI 22 ± 2.0 kg/m^2	NA	History and clinical examination	Running barefoot with a speed of 3.3 m/s (± 5%) on a 13 m EVA foam runway - Kinematics measurements: • Hip joint add, tibia IR and subtalar joint eversion; • At touchdown and max. Kinetics measurements: • Pressure distribution of the feet • Max. force normalized to bodyweight and relative force-time integral	- ITBS vs CG I ≥AddTD, diff. = 3.2° p = 0.49, AddMax diff. = 2.2° p = 0.081, IRTD diff. = 1.5° p = 0.44, IRMax diff. = 1.1° p = 0.355, EVTD diff. = 1.2° p = 0.318, EVMax diff. = 1.0°, p = 0.359 - ITBS vs CG II => AddTD diff. = 3.8° p = 0.008, AddMax diff. = 3.0° p = 0.024, IRTD diff. = 1.8° p = 0.03, IRMax diff. = 1.3° p = 0.193, EVTD diff. = 2.7° p = 0.053, EVMax diff. = 1.2° p = 0.311 - ITBS vs CG III ≥ AddTD diff. = 3.9° p = 0.006, AddMax diff. = 3.0° p = 0.008, IRTD diff. = 2.0° p = 0.008, IRMax diff. = 1.8°, p = 0.052, EVTD diff. = 3.2° p = 0.002, EVMax diff. = 1.9° p = 0.081 Pressure measurements also depend on the matching process, with decreasing (NS) between ITBS and CG after refining the process (ITBS vs CG I ≥ ITBS vs CG III)	Department of Sports Medicine, Medical Clinic University of Tübingen, Tübingen Germany	Biomedical; iliotibial band

Continued next page

Table II. Contd

Study (y)	Design	Population[a]	Follow up	Diagnostic ITBS	Exposure/treatment	Analyses/outcome[b]	Setting	Theoretical perspective
Grau et al.[96] (2011)	Case referent	N = 36; 26 M, 10 F ITBS group runners: - N = 18; 13 M, 5 F - Age 36 ± 7 y - Height 177 ± 8 cm - Weight 71 ± 12 kg - BMI 23 ± 3 kg/m^2 - Runner type • 1 forefoot (forefoot-heel-forefoot) • 17 rearfoot (heel-forefoot) Training speed 3.3 m/s CG healthy runners: - N = 18; 13 M, 5 F - Age 37 ± 9 y - Height 177 ± 9 cm - Mass 70 ± 10 kg - BMI 22 ± 2 kg/m^2 - Runner type: • 1 forefoot (forefoot-heel-forefoot) • 17 rearfoot (heel-forefoot) - Training speed 3.3 m/s	NA	History, presentation and positive Ober test or Noble compression test	Running barefoot with a speed of 3.3 m/s a 13 m EVA foam Kinematic measurements: - Max. values (°), ROM values (°) and max. velocity values (°/s) of sagittal hip motion and frontal hip motion, sagittal knee motion, sagittal ankle motion and frontal rearfoot motion for CG and ITBS subjects - Timing of max. joint angle excursions relative to the % of the ROP; joint coordination: ≥ hip flexion, hip add, KF, internal tibial rotation, ankle flexion and RFEV for control group and ITBS subjects	- Kinematic evaluation: • ITBS group: less hip add (at the point of max. add at about 32% of ground contact) and frontal ROM at the hip joint in runners with ITBS - Kinetic evaluation • ITBS group: max. hip flexion velocity and max. KF velocity were lower • No difference between groups with regard to ankle joint and rear foot motions - Lack of joint coordination (earlier hip flexion [$p < 0.05$] and a tendency toward earlier KF) ITBS compared with CG subjects	Department of Sports Medicine, Medical Clinic University of Tübingen, Tübingen Germany	Biomedical; fad pad compression beneath the iliotibial band
Noehren et al.[22] (2007)	Case referent	N = 400; 100% F runners, minimum 20 miles/wk; 18–45 y Incidence rate of ITBS 16% among all reported injuries ITBS group: - N = 18; 100% F - Age 26.8 y - Monthly mileage 96.2 - BMI 21.9 kg/m^2 CG: - N = 18; all F - Age 28.5 y - Monthly MRD 99.3 - BMI 22.1 kg/m^2	2 y	NF	An instrumented gait analysis: - Peak moments of hip, knee and rear foot angles during stand phase of running - Averaged over the five running trails (25 m of 3 m/s [± 5%]) and averaged across groups	Significant - Hip add peak; ITBS 14.1 ± 2.5°, CG 10.6 ± 5.1°; $p = 0.01$ - Knee IR peak ITBS 3.9 ± 3.7°, CG 0.02 ± 4.6°; $p = 0.01$ - Femur in lab.; peak –4.6 ± 6.9°, CG 1.3 ± 7.5°; $p = 0.02$ - Moment: hip abd, knee external rotation and rear foot inversion; NS - Tibia in lab.; peak and KF at heel strike; NS	NF	Biomedical: iliotibial band

Continued next page

Table II. Contd

Study (y)	Design	Population[a]	Follow up	Diagnostic ITBS	Exposure/treatment	Analyses/outcome[b]	Setting	Theoretical perspective
Pinshaw et al.[16] (1984)	Cohort: longitudinal prospective	N = 210; sex NF - Consecutive pts over a period of 6 mo - 14 were excluded because of no running athletes: - N = 196; 169 M 27 F Four common injuries (78%): 1. Peri-patellar pain syndrome (runner's knee); n = 42 2. Shin splints; n = 36 3. ITBS group n = 24; sex = NF - 2% combination with runner's knee/shin splints 4. Chronic muscle injuries; n = 11	8 wk	Noble compression test	Treatment ITBS; applicable advice: - Running shoes: change to 'soft' running shoes - Foot orthoses and shoe alterations: the outside heel flare of the shoe corresponding injured side removed - Leg-length discrepancies; full correction at the heel, 50% correction mid-sole and 25% correction at the ball of the foot - Training methods: appropriate advice in training distances, running speed, amount of hill running and adequate rest days - Ice application: encouraged to apply ice twice a day for 30 min	ITBS pts: - 50% previous seen a GP, orthopaedic surgeon or non-medical practitioner - Not found below age of 20 y and evenly distributed between all groups >20 y - ITBS was common among athletes who run <1 y, running 41–80 km/wk, 70–80% middle-distance runners, 70% performing stretching exercise <10 min/day, knee varus 52% and normal 48%, patellar medially pointing 10% and normal 89% - Foot alignment 12% normal, 35% mild, 47% moderate and 6% severe varus - Running shoe: 28% Adidas, 30% New Balance, 23% Nike Treatment ITBS: 78% runners were seen 8 wk later: - 44% were 100% cured, 67% followed advice; - 22% were 75% cured, 75% followed advice; - 11% were 50% cured, 50% followed advice; - 7% were 25% cured, 25% followed advice; - 16% were 0% cured, 75% followed advice	Cape Town SAB Sports Injury Clinic, Cape Town, South Africa	Biomedical: iliotibial band
Taunton et al.[17] (2002)	Cross sectional	N = 2002; 926 M, 1076 F runners; ITBS group: - N = 168; 63 M, 105 F - Age 32.2 y - Activity history 7.3 y - Weekly h 4.9 M: • Height 169.9 cm • Weight 75.7 kg	NA	NF	Biomechanical assessment: - Leg length inequality; >0.05 - Leg alignment; genu valgus/genu varum - Q angle; >16° - Patellar position; Patellar squinting through femoral	- Leg length inequality n = 17 - Leg alignment • valgus n = 25 • varus n = 54 - Q angle n = 3 - Patellar position • patellar squinting n = 13 - Arch position • pes planus n = 25	AMSMC University of British Colombia, Vancouver, BC, Canada	NF

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Table II. Contd

Study (y)	Design	Population[a]	Follow up	Diagnostic ITBS	Exposure/treatment	Analyses/outcome[b]	Setting	Theoretical perspective
		• BMI 23. 7 kg/m^3 F: • Height 158.1 cm • Weight 60.0 kg • BMI 21.2 kg/m^3			anteversion - Arch position (low/normal/high) History and anamnestic - Previous injury to same anatomical area - Running ability on level of competition; recreational/ competitive (provincial, national or international)	• pes cavus n = 12 <34-y-old risk factor for men; OR 2.77 (95% CI 1.42 to 5.40)		

a Population data are presented as means, means ± SDs and 95% confidence intervals where stated.

b Analyses/outcome data are presented as means ± SDs where stated.

abd = abduction; **add** = adduction; **AddMax** = maximal hip add; **AddTD** = hip add at touchdown; **AMSMC** = Allan McGavin Sports Medicine Centre; **BMI** = body mass index; **CG** = control group; **CI** = confidence interval; **diff.** = difference; **ERM** = knee external rotation moment; **EVA** = ethylene vinyl acetate; **EVMax** = maximal subtalar joint eversion; **EVTD** = subtalar joint eversion at touchdown; **F** = female; **GP** = general practitioner; **HABM** = hip abductor moment; **HADD** = hip adduction angel; **IR** = internal rotation; **IRMax** = maximal internal rotation of the knee; **IRTD** = knee internal rotation at touchdown; **ITBS** = iliotibial band syndrome; **KF** = knee flexion; **lab.** = laboratory; **M** = male; **max.** = maximum; **MRD** = monthly running distance; **NA** = not applicable; **NF** = not found; **N/n** = number; **NS** = not significant; **NSAIDs** = non-steroidal anti-inflammatory drugs; **OR** = odds ratio; **pts** = patients; **rehab.** = rehabilitation; **reps.** = repetitions; **RFEV** = rear foot eversion angle; **RFIM** = peak rear foot invertor moment; **ROM** = range of motion; **ROP** = roll over process; ? indicates the setting was possibly a laboratory but was not explicitly mentioned/found in this study.

Table III. Observational study diagnostics of iliotibial band syndrome in runners

Study (y)	Design	Population[a]	Diagnostics ITBS	Exposure/treatment	Analyses/outcome[a]	Setting	Theoretical Construct
Ferber et al.[100] (2010)	Cohort: cross sectional	N = 300; 125 M, 175 F Recreational athletes; minimal 30 min activity, 3 × wk: - N = 250 injured; 104 M, 146 F ITBS group: - N = 31; 10 M, 21 F - Age 32.3 ± 9.7 y - Height 167 ± 29.2 cm - Weight 73.7 ± 21.4 kg	NF	Ober test and modified Thomas test	Ober test: Overall = –24.59° ± 7.27°, n = 600 Negative = –27.13° ± 5.53°, n = 432 Positive = –16.29° ± 6.87°, n = 168 Critical criteria = –23.16°, inter-agreement = 95% Modified Thomas test: Overall = –10.60° ± 9.61°, n = 600 Negative = –15.51° ± 5.82°, n = 382 Positive = –0.34° ± 7.00°, n = 208 Critical criteria = –6.69°, inter-agreement = 97.6%	Running Injury Clinic and Faculties of Kinesiology and Nursing, University of Calgary. Calgary, AB, Canada	NF

a Population data and Analyses/outcome data are presented as means ± SDs where stated.

F = female; **ITBS** = iliotibial band syndrome; **M** = male; **NF** = not found.

runway at a speed of 3.3m/s. Analysis showed that the differences in kinematic variables (hip joint adduction, tibia internal rotation and subtalar joint eversion) became more pronounced in comparisons with more closely matched controls. Hip joint adduction at touchdown was significantly lower in the ITBS group than in the three CGs. Maximal adduction at the hip was lower in the ITBS group and was significantly different from that in the CG II and CG III groups. Internal knee rotation at touchdown was significantly lower in the ITBS group than in the three CGs, but the maximal knee internal rotation was not significantly different. Subtalar joint eversion was significantly lower at touchdown in the ITBS group than in CG III. The differences in kinetic variables (rearfoot loading and forefoot loading) became less pronounced in comparisons with more closely matched controls. Only the lateral rearfoot (force time integral) and medial forefoot (maximum force normalized to bodyweight) forces were significantly greater and lower in the ITBS group than in the CG I group, respectively.[94] In 2007, Noehren et al.[22] followed up 400 runners for 2 years, as part of a larger prospective investigation of lower limb injuries in female runners. Eighteen runners developed ITBS and their running kinematics and kinetics were compared with those of age-, body mass index- and monthly mileage-matched controls. The subjects wore standard neutral running shoes and ran along a 25m runway at a speed of 3.7m/s (± 5%), striking a force plate at its centre. The ITBS group exhibited greater peak hip adduction, peak knee internal rotation and femoral external rotation, and remained more adducted throughout stance than did the control group. No difference was found in rearfoot eversion, tibia rotation (in global) and knee flexion. Group analyses in the ITBS group showed that subjects (n = 4) with a greater peak rearfoot motion than the mean, showed a higher tibial internal rotation.[22] In a retrospective study, Taunton et al.[17] analysed data on 2002 individuals with runningrelated injuries, including 63 men and 105 women with ITBS. The most common overuse running injury was patello-femoral pain syndrome (PFPS), followed by ITBS. Varus and valgus knee alignment were present in 33% and 15% of the ITBS group, respectively, and the length of the right versus left leg varied by 10%. Multivariate analysis revealed younger age (mean <34 years) to be a risk factor for ITBS in men; odds ratio of 2.77 (95% CI 1.42 to 5.40). Risk factors for ITBS in women were not identified.[17] Ferber et al.[95] investigated female runners, comparing 35 females who had previously sustained ITBS with 35 healthy age- and runningdistance- matched healthy females. All the subjects involved in this study were part of a larger, ongoing prospective investigation of female runners (n = 400; ages 18–45 years, minimum running distance of 30km/wk). Subjects ran along a 25m runway at a speed of 3.7m/s (± 5%), striking a force plate at its centre. The footwear was not described. Women with ITBS had a greater peak hip adduction angle, knee internal rotation angle and peak rearfoot invertor moment than the controls.[95] Grau et al.[96] subsequently investigated the same group of runners with ITBS, as in their earlier study.[94] The subjects, all rearfoot strikers, ran barefoot along a 13m EVA foam runway at a pre-specified speed of 3.3m/s. In the kinematic evaluation, hip adduction was found to be smaller in the ITBS group (n = 18) compared with the sex-, height- and weight-matched control runners (n = 18). Furthermore, maximum hip flexion velocity and maximum knee flexion velocity were lower in runners with ITBS. Joint coordination, expressed as earlier hip flexion and a tendency toward earlier knee flexion, was also poorer in the ITBS group. No differences were found between the groups with regard to ankle joint and rearfoot motion.[96] Pinshaw et al.[16] studied a series of 169 running injuries to determine the nature of the common injuries, the type of runners with the different injuries, specific factors causing the most common injuries and the response of these injuries to correction of the biomechanical abnormalities believed to have caused them. Over 6 months they diagnosed 24 runners with ITBS; in 37% of these runners one leg was shorter than the other, and these runners had injuries such as ITBS, shin splints and PFPS. The prevalence of genu varum was similar in runners with these injuries, but runners with ITBS were more likely to have normal patellar alignment. Pinshaw at al.[16] concluded that runners with ITBS were more likely to have a 'normal' lower limb structure than runners with either PFPS or shin splints.

Training and Shoes

Neither the type of training (as a percentage of time spent running long distances at low speed) nor the training surface influenced the type of injury sustained in the study of Pinshaw et al.,[16] although most runners with ITBS spent more than 90% of their training time running long distances at low speed wearing 'New Balance' shoes and mainly running on tar and dirt roads.[16]

Summary

Studies of the aetiology of ITBS in runners provide limited or conflicting evidence, and it is currently not clear whether hip abductor weakness has a role in ITBS. The kinetics and kinematics of the hip, knee and ankle/foot appear to be different in runners with and without ITBS,[22,94-96] although results regarding the kinematics of adduction of the hip, (maximal) internal rotation of the knee and the inversion and eversion of the ankle/foot are conflicting.[22,94-96] There is limited evidence that runners with ITBS have poor joint coordination, showing earlier hip flexion and a tendency toward earlier knee flexion.[22,94-96] These biomechanical studies involved small samples, and data seemed to have been influenced by the sex, height and weight of participants. Many runners with ITBS have one leg shorter than the other,[16,17] but have a normal patella alignment.[16] These runners tended to train by running long distances at low speed, wearing 'New Balance' shoes, and to run on tar and dirt roads.[16] Young (aged <34 years) male runners were at the highest risk of sustaining an ITBS injury.[17] However, the small size of these uncontrolled studies[16,17] means that firm conclusions cannot be drawn about factors that could promote ITBS.

Table IV. Observational studies and randomized clinical trials: treatment of iliotibial band syndrome in runners

Study (y)	Design	Population[a]	Follow-up[a]	Diagnostic ITBS	Exposure/treatment	Analyses/outcome[a]	Setting	Theoretical Construct
Gunter and Schwellnus[91] (2004)	RCT	N = 9; sex NF Runners with ITBS Experimental group: - N = 9; sex NF - Age 29.0 ± 6.5 y - Height 176.4 ± 8.3 cm - Weight 73.3 ± 7.3 kg - Total weekly distance running: 83.3 ± 9.7 km - Best 10 km time 46.8 ± 6.9 min CG: - N = 9; sex NF - Age 28.9 ± 5.0 y - Height 177.9 ± 11.1 cm - Weight 70.5 ± 8.0 kg - Total weekly distance running: - 82.5 ± 9.3 km - Best 10 km time 46.6 ± 6.7 min	14 days	History, presentation, clinical examination, Noble compression test and test of Renne	EG: - 40 mg methylprednisolone acetate mixed with local anaesthetic CG: - Local anaesthetic Treadmill running test: - VAS per min - Total pain during running - Days 0, 7 and 17	There was a tendency (p = 0.07) for a greater decrease in total pain during the treadmill running in EG vs CG from day 0 EG = mean 222 (SEM 71), CG = mean 197 (SEM 31) to day 7 EG = mean 140 (SEM 87), CG = mean 178 (SEM 76) There was a significant (p = 0.01) decrease of total pain during running from day 7 EG = mean 140 (SEM 87), CG = mean 178 (SEM 76) to day 14 EG = mean 103 (SEM 89), CG = mean 157 (SEM 109) in the EG vs CG)	Sports Medicine Clinic of a Staff Model Health Maintenance Organization in South Africa	Biomedical: tissue beneath the iliotibial band
Hariri et al.[98] (2009)	Cohort: longitudinal retrospective	N = 11; 7 M, 4 F pts with ITBS - Age of onset symptoms: • 29 ± 8 y - Age at surgery: • 32 ± 5 y - BMI 24 ± 47 kg/m^3	38 ± 16 mo	History, presentation and Noble compression test	Iliotibial band bursectomy by a single surgeon	Post-operative - Tegner activity score: • Pre-operative • Post-operative 5 ± 2 (NS) - VAS • Pre-operative 8 ± 2 • Post-operative 2 ± 3 - Lysholm score: excellent 7 pts, good in 4 pts - IKDC 88 ± 11 • Surgical outcome; 6 pts completely satisfied, 3 mostly satisfied, 2 somewhat satisfied	Division of Sports Medicine, Department of Orthopedic Surgery, Boston, MA, USA	Biomedical: Bursa

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Table IV. Contd

Study (y)	Design	Population[a]	Follow-up[a]	Diagnostic ITBS	Exposure/treatment	Analyses/outcome[a]	Setting	Theoretical Construct
Michels et al.[99] (2009)	Cohort: longitudinal prospective	N = 36: 21 M,15 F Pts with ITBS, 33 pts for follow-up: - N = 33; sex NF - Age 31.1 range 19–44 y - Suffering from ITBS for 18 mo preoperatively, range 1–7 y - Recreational or professional athletes: running (n = 22), triathlon (n = 5), cycling (n = 4), athletics (n = 3), rugby (n = 3), soccer (n = 1), swimming (n = 1), fencing (n = 1) and basketball (n = 1)	2 y and 4 mo, at least 6 mo	Clinical findings	Standardized arthroscopic technique, limited to the resection of lateral synovial recess: 16 right knees, 22 left, 2 pts bilaterally	Running: - 2 mo post-operative 74.2% start slow running, 100% at 3 mo Results: - 28 (80%) excellent, 6 (17.1%) good, 1 (2.9%) fair Satisfaction - mean 6, range 6–10 points Complications: - 1 pt cartilage lesions of the femoral condyle, 2 pts with a menisci lesion, 1 pt calcified loose body in the lateral synovial recess, 1 developed a haematoma	Bordeaux Merignac Sports Clinic	Biomedical: Fibrous and fat tissue
Schwellnus et al.[92] (1992)	RCT	N = 17; sex NF Pts with unilateral ITBS Group A: - N = 9; sex NF - Age 25 ± 6 y - Duration of injury 23 ± 17 wk - Years of running 7.7 ± 5.5 - Weekly training distance 45 ± 15 km - Grade of injury 3.4 ± 0.5 units Group B: - N = 8; sex NF - Age 29 ± 5 y - Duration of injury 74 ± 95 wk - Years of running 5.4 ± 6.2 - Weekly training distance 64 ± 30 km - Grade of injury 3.4 ± 0.5 units	14 days	History, presentation and test of Noble	Treatment: - Rest - Ice; twice daily local application 20 min - Basic physiotherapy • Daily stretching of the iliotibial band • Ultrasound on day 3, 4, 5, 6, 7 and 10 - Deep transverse friction for group A on days 3, 5, 7 and 10	Daily pain recall: - The mean daily pain scores recorded for overall pain over three treatments periods (days 0–2, days 3–6 and days 7–14) significantly decrease for both group with no difference between group A and B Treadmill running: - Total pain experienced during running (area under the pain vs time curve) was not significantly decreased between the groups of any of the days (days 0, 3, 7 and 14) - Significant decrease in the pain values and maximum pain experienced (%) over the treatment period. But not significant between groups	Sports Injury Clinic at the University of Cape Town Sports Center, Cape Town, South Africa	Biomedical: Under the iliotibial tract over the lateral epicondyle

Continued next page

Table IV. Contd

Study (y)	Design	Population[a]	Follow-up[a]	Diagnostic ITBS	Exposure/treatment	Analyses/outcome[a]	Setting	Theoretical Construct
Schwellnus et al.[90] (1991)	RCT	N = 43; sex NF Pts with unilateral IBTS Group 1: - N = 13, sex NF - Age 22 ± 5 y - Weight 74 ± 5 kg - Height 181 ± 3 cm - Years of running 10 ± 5 - Duration of symptoms 6.8 ± 7.1 wk - Weekly training distance 44 ± 29 km - Training speed 4.9 ± 0.3 min/km - Grade of injury 3.2 ± 0.4 units Group 2: - N = 14, sex NF - Age 24 ± 6 y - Mass 72 ± 6 kg - Height 181 ± 6 cm - Years of running 5 ± 5 - Duration of symptoms 6.1 ± 6.1 wk - Weekly training distance 48 ± 33 km - Training speed 4.6 ± 1.0 min/km - Grade of injury 3.1 ± 0.5 units Group 3: - N = 16, sex NF - Age 22 ± 2 y - Weight 68 ± 7 kg - Height 178 ± 4 cm - Years of running 6 ± 6 y - Duration of symptoms 7.4 ± 13.1 wk - Weekly training distance 39 ± 14 km - Training speed 4.6 ± 0.8 min/km - Grade of injury 3.2 ± 0.4 units	7 days	Anamnesis and compression test of Noble	Treatment: - Rest - Ice; twice daily local application - Physiotherapy; day 3 till day 7 • Daily stretching Iliotibial band; • Daily ultrasongraphy; • Deep transverse friction on days 3, 5 and 7 - Medication • Group 1; placebo capsule; 3 ×/day • Group 2; 50 mg. diclophenac sodium; 3 ×/day • Group 3; 400 mg ibuprofen, 500 mg paracetamol (acetaminophen) and 20 mg codeine phosphate; 3 ×/day	Daily 24 h recall pain: - Decreased significantly for the three groups over the treatment period • Group 3 ≥ significantly decrease from day 0 to day 3 • Group 1 and 3 ≥ significantly decreased from day 3 to day 7 • All groups ≥ significantly decreased from day 0 to day 6 - No difference between groups Treadmill running test (day 0, 3 and 7) - Total running time did not differ significantly between groups on each of the test days. Total distance run did not differ significantly on each of the test days - In all three groups the total distance run, did not change significantly from day 0 to day 3, but did significantly change from day 3 to day 7. Group 3 distance significantly increased from day 0 to day 7 - Group 3 improved their total running time and distance from day 0 to day 7 and group 1 and group 2 improved from day 3 to day 7 - In all groups the area under the pain vs time curve decreased from day 0 to day 7	Two sports injury clinics, South Africa	Biomedical: Under the iliotibial tract over the lateral epicondyle

a Population, follow-up and analyses/outcome data are presented as means ± SDs where stated.

BMI = body mass index; **CG** = control group; **EG** = experimental group; **IKDC** = International Knee Documentation Committee; **ITBS** = iliotibial band syndrome; **Pt/s** = patient/s; **VAS** = visual analogue scale.

Diagnosis

ITBS in runners tend to be diagnosed on the basis of the history and presentation,[90-92,94,96-98] complemented by clinical findings.[91,94,97,99] In most studies,[16,90-92,96-98] the Noble compression test is used to confirm the diagnosis of ITBS. Supplementary tests such as the Ober test[118] and the test of Renne[8] can be used to verify ITBS.[91,96,100] See tables II–IV and figure 1. The absence of any other signs in the knee such as effusion, joint line tenderness or a positive McMurray's test is often confirmed/rejected with MRI.[17,93,94,96,99] The Noble[109] compression test confirms the presence of ITBS.[109] The subject's knee is flexed to 90˚ then pressure is applied to the lateral epicondyle or a 1–2 cm proximal to it and then the knee is gradually extended. At 30˚ flexion the patient will complain of severe pain over the lateral epicondyle; the pain has the same quality as that experienced when running.[109] The Ober test measures the flexibility of the iliotibial band.[118] The subject is positioned on the side with the extremity to be tested facing upward. The examiner flexes the knee to be tested to 90˚ and abducts and extends the hip so that the hip is in line with the trunk. The examiner then allows the force of gravity to cause the extremity to adduct as far as possible. The degree of adduction of the hip reflects the flexibility of the iliotibial band.[100] The Renne test evokes the pain experienced during running; the subject is asked to stand on the affected leg while the knee is held in a 30–40˚ flexion.[8] Two studies[90,92,105] classified the severity of ITBS using the 'injury grade' of Lindenberg et al.[105] This system has four grades of pain as follows: (i) pain comes on after running, but does not restrict distance or speed; (ii) pain comes on during running, but does not restrict distance or speed; (iii) pain comes on during running and restricts distance or speed; and (iv) pain is so severe that it prevents running.

Muscle/Ligament Flexibility

In a cross-sectional study, Ferber et al.[100] established normative values for the flexibility of the iliotibial band and iliopsoas muscle, an aspect that is important in the management of ITBS.[22,95,96] Using a digital inclinometer, the iliotibial band flexibility (Ober test) and the iliopsoas muscle flexibility (modified Thomas test) were determined in 300 athletes (125 men and 175 women): 250 with ITBS and 50 controls. In the modified Thomas test,[100] the subject sits on the end of the plinth, rolls backwards onto the plinth and then holds both knees to the chest. The subject holds the contralateral hip in maximal flexion with the arms, while the test limb is lowered toward the floor. The degree of extension of the hip reflects the flexibility of the iliopsoas muscle.[78] The results showed an average iliotibial band flexibility of -24.59˚ and iliopsoas flexibility of -10.60˚. The critical criteria for the iliotibial band and iliopsoas flexibility were determined to be -23.16˚ and -9.69˚, respectively.[100]

Summary

Most studies used clinical tests to diagnose,[16,90-92,94,96-99] classify[16,17,90,92] and/or evaluate [90-92] ITBS in runners. These tests would appear not to have been validated for this patient group but seem to have a good face validity. Ferber et al.[100] provided normative data for the Ober test and the Modified Thomas test. Only two studies[96,100] used the Ober test to evaluate runners with ITBS; no studies have described the use of the modified Thomas test in the management of ITBS.

Treatment

Conservative

In a randomized controlled trial (RCT), Schwellnus et al.[90] investigated the effect of initial treatment (day 0–7; rest, ice application and medication) in 43 patients with unilateral ITBS. All subjects received physical therapy consisting of ultrasound, deep transverse friction massages (DTFM) on days 3, 5 and 7, and daily stretching of the iliotibial band. Medication was delivered over the 7 days in a double-blind, placebocontrolled fashion. Group 1 was given a placebo anti-inflammatory medication, group II an anti-inflammatory agent and group III a combined anti-inflammatory/analgesic. Compared with the other groups, in group III, pain during running significantly decreased from day 3 onward and running time/distance on the treadmill running test significantly increased from day 0 to 7.[90]

Schwellnus et al.[92] investigated the therapeutic benefit of DTFM. Twenty subjects with ITBS (>14 days' duration) were randomly divided into two groups. Both groups received treatment consisting of rest, ice twice a day and physical therapy (daily stretching of the iliotibial band and 5 minutes of low-dose ultrasound therapy) on days 3, 5 and 7. The intervention group was also given DTFM for 10 minutes on days 3, 5 and 7. The results showed that daily pain and treadmill running pain were significantly reduced in both groups after treatment. The authors concluded that the addition of DTFM did not alter the therapeutic outcome of ITBS.[92]

In a RCT, Gunter and Schwellnus[91] investigated 18 runners with acute-onset ITBS (<14 days' duration). Subjects were randomly allocated into two groups: group I received a corticosteroid injection and group II received a placebo injection. Subjects were instructed not to run for 14 days following the injection and to apply ice to the area for 30 minutes every 12 hours. Running pain was significantly decreased in the group that received the corticosteroid injection.[91]

Fredericson et al.[97] tested the effectiveness of a 6-week standardized rehabilitation programme in 10 female and 14 male runners with ITBS. The programme consisted of a local application of ultrasound with corticosteroid gel for the first two sessions. All patients were instructed to stretch the iliotibial band three times a day. Hip abduction exercises and pelvic drops to strengthen the gluteus were started at 1 set of 15 repetitions over a course of several weeks and increased to the goal of 3 sets of 30 repetitions. The patients were instructed to increase the workout by 5 repetitions per day if there was no significant post-workout soreness the following day. Nonsteroidal anti-inflammatory drugs were prescribed until the patients were pain free during daily activities. All subjects were instructed to discontinue running and any other activities that continued to cause pain. The investigators found a mean increase of 34.9% and 51.4% in the injured limb of the hip abductor torque for females and males, respectively. Twenty-two of the 24 athletes were able to return to running after 6 weeks of rehabilitation.[97] Pinshaw et al.[16] gave runners with ITBS the following advice about:

1. Running shoes: change to softer running shoes, use of in-shoe supports and shoe alterations and/or removal of the outside heel flare of the shoe for the injured side.
2. Leg-length discrepancies: adapt shoe of the shorter leg by adding material to the mid-sole to ensure 100% correction at the heel, 50% correction in the mid-sole and 25%correction at the ball of the foot.
3. Training methods: if appropriate, one could reduce training distance, decrease running speed and amount of hill running, and one could incorporate a sufficient number of days for recovery.
4. Ice application: apply ice to the injured area for 30 minutes twice a day.
   After 8 weeks, 44% of the runners with ITBS were 100% cured, 22% were 75% cured and 34% were 50% cured or less.[16,97]

Surgery

Hariri et al.[98] described the effect of bursectomy in 11 consecutive patients with ITBS (7 men and 4 women; mean – standard deviation age at symptom onset 29 ± 8 years) who had persistent (>6 months) symptoms despite conservative treatment. After a minimum of 20 months follow-up, all patients were able to return to their pre-injury activity levels and reported less pain (11-point visual analogue scale score decreased by 6 points). The majority of patients were highly satisfied with the results of the procedure.[98]

Michels et al.[99] evaluated arthroscopic resection of the lateral synovial recess as treatment for resistant ITBS. Thirty-six patients underwent 38 procedures; 33 patients (15 women, 21 men; mean age 31.1 years, range 19–44 years; 35 knees) were followed up for at least 6 months (mean 2 years and 4 months). Prior to surgery, all patients had been treated consevatively for at least 6 months with rest, correction of training error, shoe modification, physical therapy and local infiltration with steroids. The patients had suffered from ITBS for 18 months (range 1–7 years). The subjective functional results after surgery were excellent (80%), good (17.1%) and fair (2.9%), and patients were satisfied with the procedure (mean score 9 of 11). In retrospect, all but one patient would still have had the procedure.[99]

Summary

Overall, the results of the five studies[16,90-92,97] on the conservative treatment of ITBS provided some evidence of the effectiveness of different treatment modalities; pain medication/injection, stretching of the iliotibial band, hip abduction exercises and pelvic drops to strengthen the gluteus muscles, and advice about training, shoe inlays and shoes. Two studies provided limited evidence of the beneficial effect of two different surgical interventions in selected groups of patients.[98,99]

Discussion

This extensive, quality-controlled, systematic review revealed that there is limited evidence to support a specific approach to the aetiology, diagnosis and treatment of ITBS. Only one systematic review was found,[7] but this review investigated conservative treatments only and included other sufferers of ITBS beside runners and included only RCTs.We included observational studies as well to identify other potentially relevant types of treatment. Other narrative reviews[9,23-28,31-48] merely reported the subjective results achieved with the ITBS management protocol used by the authors.

Methodological Quality

The Cochrane Collaboration criteria were used to assess the methodological quality of the studies identified by the computerized database search.[29] While the usefulness of quality control is disputed,[119,120] and it is difficult to determine how to weight each item in an overall QS,[121] sum scores are considered helpful in a systematic review to make a distinction between studies with both a low and high risk of bias, and there is empirical evidence to support this view.[122] We evaluated the QS of the studies in order to gain insight into the risk of bias within the results[121] and excluded studies of poor methodological quality to enable us to draw meaningful conclusions.

A point of concern is the lack of blinding of treatment allocation in three RCTs,[90-92] which could affect results.[123] Inadequate or unclear allocation concealment can lead to higher estimated treatment effects. However, it is not generally possible to predict the magnitude or even the direction of possible selection bias and consequent distortions of treatment effects, as a result of inadequate or unclear allocation concealment [123] The methodological flaws of poor-quality observational studies mainly concerned the poor description of the population,[10,12,19,21,101,104,105,107-117] selection bias,[10,12,19,21,101,103-117] and the poor description of potential confounding variables.[10,12,21,103-109,111-117] These aspects help readers understand the applicability of the results, and the lack of this information limits generalizability.[124] The study by Grau et al.[94] showed that, in addition to generally accepted confounders, participants' sex, height and weight also affected study outcomes.

To summarize, the poor methodological quality of the studies makes it difficult to draw firm conclusions about the management of ITBS in runners. Future studies should take into account the problems of concealing treatment allocation, the description of the population, potential selection bias and the description of confounding variables.

Pathogenesis, Diagnosis and Management of Iliotibial Band Syndrome

Knowledge of the pathogenesis of ITBS is essential for providing runners with appropriate treatment and advice.[34] However, the exact pathogenesis of ITBS is still controversial. It was originally thought to be due to excessive friction between the tract and the lateral femoral condyle, leading to inflammation of the tract or bursa.[109,115] However, Nemeth and Sanders[10] found that the lateral femoral condyle is actually a lateral extension of the joint capsule and suprapatellar synovial cavity of the knee joint. In runners with ITBS, histopathology studies have revealed chronic inflammation, hyperplasia, fibrosis and mucoid degeneration of the lateral femoral recess.[10] Muhle et al.[125] found ITBS to be correlated with MRI signal intensity alterations in the fatty tissue deep in the iliotibial band. Using cadavers, Fairclough et al.[51] showed that the iliotibial band is firmly anchored to the distal femur by fibrous strands, associated with a layer of richly innervated and vascular fat. This femoral anchorage prevents the iliotibial band from rolling over the epicondyle. Eight observational studies investigated the role of muscle strength,[93,97] biomechanics,[16,17,22,94-96] training, and shoes[16] in the aetiology of ITBS. While deficits in the hip abductors are presumed to be a major factor in the development of ITBS in runners,[36] we found conflicting evidence that hip abductor weakness is important to the aetiology of ITBS in runners. Possible reasons for the different findings might be the measurement device, the variables measured, sample size and the heterogeneous population (age, sex and level of performance).[93,97] Future studies should measure hip abductor strength in more patients (>30) in a more functional way, to reflect the reality of running and include a control group.[93,97,126] Prospective studies could determine whether runners with weakness in their hip abductors are at a greater risk of developing ITBS or whether weakness of the muscle is caused by ITBS,[97] with a focus on the endurance and muscle activation patterns.[96] From studies of biomechanics (kinetics and kinematics) in runners both with and without ITBS, it is not clear whether ITBS appeared before the change in biomechanics or if a difference in biomechanics caused the ITBS. However, the results of the studies of Grau et al.[96] and Ferber et al.[95] suggest that lower extremity running mechanics do not change as a result of ITBS. In contrast, the results of Grau et al.[94] showed that biomechanical differences between healthy runners and those with ITBS do depend on the matching (weight, height and sex) of the participants. For instance, it is unclear whether there is a sex-specific biomechanical aspect to the development of ITBS in runners.[17,96] Other studies showed that differences between runners with or without ITBS might also depend on the acuity of ITBS (i.e. painful or not painful), the method of the diagnosis, running style, running experience (i.e. elite, competitive and casual), shoe, surface and speed of the runner.[127-130]

Thus, in the future, it might be advisable to consider running shoes, running surface and speed as matching variables when investigating the biomechanics of ITBS based on resulting differences in running style.[127-130] Attention should also be paid to the study design (e.g. only one study is a prospective study that focuses on kinematic deviations[22]), sample size, the age of the population and possible sex-specific differences in biomechanics, in order to generate qualitatively good studies of adequate size.

In the studies included in this review, ITBS was mainly diagnosed based on the history, signs and symptoms, and clinical findings.[90-92,94,96-99] However, in many cases, the signs and symptoms were not adequately described, which makes the validity of the diagnosis of ITBS difficult to determine in several studies.[17,93,95,100] Clinical investigations included palpation, compression test of Noble and/or the test of Renne.[16,90-92,96-98] Further research should focus on the validation of these tests for runners with ITBS. The functional running test to assess the efficacy of the treatment of ITBS seemed to be more sensitive than conventional pain-recall methods,[90] but further clinometric research is necessary to identify its reliability and responsiveness in runners with ITBS. The severity of ITBS was classified according to the 'injury grade' of Lindenberg et al.[90,92,105] This classification tool has good face validity and was validated in the study of Schwellnus et al.,[90] but no clinometric studies are available. Future studies should focus on the reliability of this tool and whether it can be used to identify subgroups of ITBS to enable more effective treatment of the condition.[131]

The flexibility of the iliotibial band and iliopsoas muscle seems to be an important aspect in the management of ITBS.[22,95,96] The Ober test and the modified Thomas test can be used in daily practice to identify runners with a high risk of ITBS and to evaluate the effect of stretching exercises as a component of ITBS treatment. Further research with these tests should focus on the differential effect of stiffness of the iliotibial band and iliopsoas muscle, and of acute, sub-acute and chronic ITBS on treatment outcomes. In the acute phase (<14 days duration), corticosteroid injection appears to be beneficial, with runners being able to run pain free within 14 days.[91] In the subacute stage (>14 days duration), a combination of anti-inflammatory/analgesicmedication appeared to be more beneficial than anti-inflammatory medication alone.[90] The use of DTFM is supported by anecdotal evidence of its effectiveness. However, it seems somewhat illogical to use friction techniques to treat an injury that might be caused by friction.[7] Schwellnus et al.[90] found DTFM in combination with ultrasound and stretching exercises to be no better than ultrasound and stretching alone,[90] as both treatment regimens reduced daily pain and pain experienced on treadmill running.

Overall, the studies confirm the benefits for the conservative treatment of ITBS in runners; pain medication/injection, stretching of the iliotibial band, hip abduction exercises/pelvic drops to strengthen the gluteus muscles and advice about training, inlays and shoes.[16,90-92,97] Unfortunately, to date, no (randomized) clinical trials have investigated the benefit of these different modalities in isolation.[7] Although iliotibial band bursectomy and arthroscopic resection of the lateral synovial recess proved effective in runners with chronic (>6 months) ITBS,[98,99] the studies investigating these techniques were small.

In summary, conservative treatment appears to be beneficial in the management of ITBS in runners, although the evidence supporting this comes from studies with small, heterogeneous samples. Further investigation of the specific clinical benefit of conservative therapies for runners with ITBS will be of great importance to the evidence-based management of this condition and to research.[7] Surgical approaches appear to be effective, and the arthroscopic technique would seem especially appropriate because it allows assessment and treatment of any intra-articular pathology. In the future, it would be interesting to compare these treatments in an RCT with more participants.

Conclusion

ITBS is a common injury of the lateral aspectof the knee in runners.[7] Although several investigations have been published, there is a paucity of research of adequate quality on the management of ITBS in runners. As the studies included in this review provided limited evidence, hard conclusions about the prevention and treatment of this injury cannot be drawn. This review shows that future research on the management of ITBS in runners should pay more attention to the methodological aspects of the study design, such as concealing treatment allocation and adequately describing the study population, exclusion criteria and confounding variables. Knowledge of the pathology of ITBS could contribute to the development of a diagnostic protocol for ITBS in runners. In addition, uniformity in the diagnostic protocol for ITBS in runners is essential for the effective management of this type of musculoskeletal injury. On the basis of the limited evidence generated in this review, treatment of ITBS should include advice about coordination and running style, choice of shoes and an appropriate running surface in combination with training to strengthen the hip muscles.

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Chapter 3

INJURIES IN RUNNERS; A SYSTEMATIC REVIEW ON RISK FACTORS AND SEX DIFFERENCES

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Abstract

Background: The popularity of running continues to increase, which means that the incidence of runningrelated injuries will probably also continue to increase. Little is known about risk factors for running injuries and whether they are sex-specific.

Objectives: The aim of this study was to review information about risk factors and sex-specific differences for running-induced injuries in adults.

Search Strategy: The databases PubMed, EMBASE, CINAHL and Psych-INFO were searched for relevant articles.

Selection Criteria: Longitudinal cohort studies with a minimal follow-up of 1 month that investigated the association between risk factors (personal factors, running/ training factors and/or health and lifestyle factors) and the occurrence of lower limb injuries in runners were included.

Data Collection and Analysis: Two reviewers' independently selected relevant articles from those identified by the systematic search and assessed the risk of bias of the included studies. The strength of the evidence was determined using a best-evidence rating system. Sex differences in risk were determined by calculating the sex ratio for risk factors (the risk factor for women divided by the risk factor for men).

Main Results: Of 400 articles retrieved, 15 longitudinal studies were included, of which 11 were considered high-quality studies and 4 moderate-quality studies. Overall, women were at lower risk than men for sustaining running-related injuries. Strong and moderate evidence was found that a history of previous injury and of having used orthotics/inserts was associated with an increased risk of running injuries. Age, previous sports activity, running on a concrete surface, participating in a marathon, weekly running distance (30–39 miles) and wearing running shoes for 4 to 6 months were associated with a greater risk of injury in women than in men.
A history of previous injuries, having a running experience of 0–2 years, restarting running, weekly running distance (20–29 miles) and having a running distance of more than 40 miles per week were associated with a greater risk of running-related injury in men than in women.

Conclusions: Previous injury and use of orthotic/inserts are risk factors for running injuries. There appeared to be differences in the risk profile of men and women, but as few studies presented results for men and women separately, the results should be interpreted with caution. Further research should attempt to minimize methodological bias by paying attention to recall bias for running injuries, follow-up time, and the participation rate of the identified target group.

Introduction

Although running has been popular since the 1970s [1], the number of runners and running events has increased steadily since 2000 [1,2]. This increase is largely due to girls and women who started running [2,3]. Running in the adult population is one of the most popular physical activities around the world and in the Western society many cities have their own recreational running event. Furthermore, running is one of the most efficient ways to achieve physical fitness, which is linked with longevity [1]. A drawback of the sport is the relatively high risk of injury, with an incidence varying between 19% and 79% [4]. This large variation is due to differences in the definition of injury, study populations, and follow-up periods [5]. Injuries diminish pleasure in exercise and lead to a temporary or even permanent discontinuation of running. Injuries furthermore lead to increased costs because of necessary medical treatment (e.g., the direct medical costs per injured runner at the emergency department is estimated at €1300 [6]), and/or absence from work. In conclusion, running is very popular in the adult population, however strategies are needed to prevent high incidences of running injuries in this group of runners.

Acute running injuries are rare, consisting mainly of muscle injuries, sprain, or skin lesions (blisters and abrasions) [7]. Eighty percent of running disorders are overuse injuries, resulting from a mismatch between the resilience of the connective and supporting tissue and running [7]. Running is one of the most common sports that give rise to overuse injuries of lower back and the leg [8]. The predominant site of leg injuries is the knee, for which the location specific incidence ranged from 7.2% to 50.0% [4]. Running injuries of the lower leg, foot and upper leg are common, ranging from 9.0% to 32.2%, 5.7% to 39.3%, and 3.4% to 38.1%, respectively [4]. Less common sites of running are the ankle, the hip/pelvis/groin and lower back, ranging from 3.9% to 16.6%, 3.3% to 11.5% and 5.3% to 19.1 respectively [4,9–11]. Poorly perfused tissues, such as ligaments, tendons and cartilage, are particularly at risk because they adapt more slowly than muscles to increased mechanical load [7]]. Hreljac [8] suggested that injury should be avoided not by minimizing the stress applied to a biological structure but by optimizing the amount and frequency of loading stress. Given the dynamic nature of the relationship between applied stress and injury, there must be an optimal level of applied stress for any biological structure [8].

Furthermore, the multifactorial model of Meeuwisse et al. showed the importance of identifying predisposing factors that make a runner susceptible for injury [12]. Identifying such factors may contribute to the development of injury prevention strategies [13], especially when these can be influenced by adequate training or by optimizing training environment.Moreover, the exact causes of running injuries are likely to be diverse [4] and possibly interacting with each other [13].

Risk factors for running injuries can be clustered into three domains, 1) personal factors (e.g. age, sex, height, genetic imprinting), 2) running/training factors (e.g. weekly running days, distance, running shoes), and 3) health and lifestyle related factors (e.g. smoking, a history of comorbidity and previous injuries) [4]. Three narrative reviews [5,14,15], published in 1992, reported the occurrence of injuries to be based on multifactorial risk factors. In their systematic review, Van Gent et al. (2007) [4] found limited evidence that older age [16], differences in lower leg length [17], a larger left tubercle-sulcus angle [17] and greater knee varus [17], greater height (in men) [18], use of alcohol [16], and a positive medical history (e.g. taken medication, high blood pressure, asthma, and nervous or emotional problems) [16] are associated with a higher risk of injury in men and women. Strong evidence was found that previous injuries were associated with lower extremity running injuries [4], but the studies used different definitions of previous injury, in terms of its location, time of occurrence, etc. Also, the recent systematic review of Saragiotto et al. [19] confirmed that previous injuries are a risk factor for new running injuries and no association between sex and running injuries was found in most of the included studies. In this systematic review [19] only prospective cohort studies were included and risk factors for general running-related injuries were determined. However, no distinction was made in the risk factors for specific running related injuries, e.g. medial tibial stress syndrome, Iliotibial band syndrome, etc.

Differences in the health status of women and men are of increasing concern to European health policymakers and are becoming a subject of growing interest to researchers [20]. The injury patterns between men and women differ and there are several reasons for the differences in injury rates, related to anatomic and physiologic differences [21].

Two recent Dutch prospective studies of novice runners [10,22] pinpointed at possible differences in injury risk profiles of men and women. In a study of runners (n = 629) who were preparing for a 6.7-km run, a younger age and lack of running experience were significant risk factors for running injuries in men, whereas lack of running experience, a higher body mass index (BMI), and earlier participation in sports without axial pressure (swimming and cycling) were risk factors for running injuries in women [10]. A subsequent study of a different cohort of novice runners (n = 532) also showed sex-specific risk factors, but the results were contradictory: significant risk factors for men were previous injuries in the past year, higher BMI, and earlier participation in sports without axial pressure, whereas in women a positive navicular drop test was the sole risk factor in adjusted analyses [22]. However, the statistical analysis used in these two studies, stepwise multiple regression, is questionable [23] and more research is needed to clarify the sex difference in risk profile.

A previous study from Canada also reported sex differences in risk factors for running injuries. A BMI of > 26 kg/m^2 was reported as protective in men, whereas age younger than 31 years was protective in women; running once a week and age older than 50 years were risk factors in women [24].

From the above, it can be appreciated that it is difficult to draw conclusions about the risk factors for running injuries in general, for specific running injuries, and possible differences in risk profile between men and women. Earlier reviews [4,5,14,15] need to be updated to identify all possible factors that may predispose a runner for injury and enabling future researchers to develop, potentially sex-specific, interventions to

prevent running-related injuries [13].
The present literature synthesis aims to review current evidence for risk factors for runningassociated injuries in adults and to determine whether risk factors for such injuries differ between men and women.

Methods

We used the MOOSE statement to report our systematic review of observational studies and the STARLITE statement to report our literature search [25,26].

Search Strategy

Four bibliographical databases, namely, CINAHL (1982 to 26 December, 2012), EMBASE (1947 to 1 January, 2013), PubMed (1940 to 26 December, 2012), and Psych INFO (1806–1 January, 2013), were searched using search strings developed by the first author and the librarian expert (AT) of the Radboud University Nijmegen Medical Center. The following search terms (Mesh, title- and/or abstract words) were used to identify the study population in combination with lower extremity injuries: running, track and field, jogging and lower limb, lower extremity, leg-, hip-, knee-, ankle- and foot injuries, soft tissue injuries, musculoskeletal pain, bursitis, sprains and strains, tendinopathy, tendinitis, Iliotibial band syndrome, patellofemoral pain syndrome, and plantar fasciitis. Keywords used to identify a relevant study design were cohort studies, longitudinal studies, follow-up, retrospective-, observational-, prospective studies, risk factors, and etiology. For the PubMed search, see Appendix 1. The search strings of the other databases are available upon request from the authors.

APPENDIX 1. Search terms PubMed

(Running[Mesh] OR "Track and Field"[Mesh] OR Runn[tiab] OR Jogg*[tiab] OR "Track and Field"[tiab])*
AND ("Leg Injuries"[Mesh] OR "Hip Injuries"[Mesh:noexp] OR "Knee Injuries"[Mesh:noexp] OR "Ankle Injuries"[Mesh] OR "Foot Injuries"[Mesh] OR ((Injur[tiab] OR pain[tiab] OR "Bursitis"[Mesh:noexp] OR Bursitis[tiab])*
AND (Lower limb[tiab] OR Lower limbs[tiab] OR Lower extremity[tiab] OR lower extremities[tiab] OR leg[tiab] OR legs[tiab] OR hip[tiab] OR hips[tiab] OR knee[tiab] OR knees[tiab] OR ankle[tiab] OR ankles[tiab] OR foot[tiab] OR feet[tiab])) OR "Musculoskeletal Pain"[Mesh] OR "Soft Tissue Injuries"[Mesh] OR "Sprains and Strains"[Mesh:noexp] OR "Tendinopathy"[Mesh] OR Tendinitis[tiab] OR tendinopathy[tiab] OR "Iliotibial Band Syndrome"[Mesh] OR "Patellofemoral Pain Syndrome"[Mesh] OR "Fasciitis, Plantar"[Mesh] OR Iliotibial Band Syndrome[tiab] OR Patella femoral[tiab] OR shin splints[tiab] OR medial tibial stress syndrome[tiab] OR plantar Fasciitis[tiab])
AND ("Risk Factors"[Mesh] OR "etiology"[Subheading:noexp] OR Determinant[tiab] OR determinants[tiab] OR risk[tiab] OR risks[tiab] OR etiology[tiab])
AND ("Cohort Studies"[Mesh] OR Cohort[tiab] OR cohorts[tiab] OR longitudinal[tiab] OR follow-up[tiab] OR followup

Selection Criteria

Two reviewers (MvdW & JS) independently selected relevant articles, based on titles and abstracts. Full papers were retrieved if the abstract provided insufficient information to decide whether the article should be included. The selection criteria were: 1) the design indicated a longitudinal cohort study with a minimal follow-up of 1 month; 2) the objective of the study was to investigate the association between risk factors (personal factors, running/training factors and/or health and lifestyle factors) and the occurrence of lower limb injuries; 3) the study population consisted of novice runners, long-distance runners both recreational and/or competitive; 4) the article was published in a peer-reviewed journal in English or German. Studies concerning elite, professional or ultra-runners, patient populations, children, and/or young adolescents (age <18 years), or in which participants were predominantly exposed to other types of sporting activity than running (e.g. military training, triathlon, etc.) were excluded. If a study contained a mixed population of runners and patients, the results for the runners had to be presented separately in order for the study to be included. The reference lists of all identified relevant publications were checked for other relevant publications.

Quality Assessment

Articles that met the selection criteria were evaluated for risk of bias. A quality list of twelve items, based on assessment tools of the Cochrane Collaboration [27] and previous systematic reviews of risk factors for musculoskeletal disorders [28–30], was used. The list was based on generally accepted principles of etiological research and was relevant for cohort studies. Some items were adapted to the topic of interest of this review by replacing risk factors with personal factors, running/training factors, and/or health & lifestyle factors (see Table 1).

Table 1. Quality assessment check list [27-30]

Study objective

1. Positive, if the main features of the study population were described (sampling frame and distribution of the population according to age and sex).
2. Positive, if the participation rate was at least 80% of the identified target group.
3. Positive, if the participation rate at the main moment of follow-up was at least 80% or if the nonresponse is not selective (data shown).

Exposure measurements

4. Positive, if the study population consisted of subjects without symptoms or if data on symptoms are included in the statistical analysis.
5. Positive, if data on system factors, running/training-related factors, and/or health and lifestyle factors were collected using standardized methods of acceptable quality.

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Outcome assessments

6. Positive, if the follow-up period was at least 1 year.
7. Positive, if outcome data were collected using standardized methods of acceptable quality.

Analysis and data-presentation

8. Positive, if the measures of association were presented (OR/RR), including confidence intervals and numbers in the analysis.
9. Positive, if the analysis was controlled for confounding or effect modification: system factors.
10. Positive, if the analysis was controlled for confounding or effect modification: running/training related factors.
11. Positive, if the analysis was controlled for confounding or effect modification: health and life-factors.
12. Positive, if the number of cases in the final multivariable was at least ten times the number of independent variables in the analysis.

Two reviewers (DtH & MvdW) independently assessed the quality of the studies. All items were scored as positive, negative, or unclear. A positive score indicated a well-described and well-performed item. A negative score indicated that the item was described but not well performed, and unclear meant the item was unclear because insufficient information was available. For each item, the scores of the two reviewers were compared. Any difference in scoring was resolved in a consensus meeting. If consensus was not reached, a third reviewer (AW) made the final decision. A high-quality study was defined as scoring positive on > 50% of the items [28–30].

Data Extraction and Statistical Analysis

The following information was extracted from the included studies: year of publication, study design with follow-up period, injury definition, population characteristics (age, sex, body mass index, or height and weight, and the proportion of subjects analyzed in the included studies;number of subjects analyzed, divided by the number of included subjects, multiplied with 100) and the incidence of (running) injuries; injury specific or overall and, if given, sex specific.

Cohen's Kappa (K) values were calculated for the interobserver agreement between the two reviewers with regard to risk of bias. A Kappa value of > 0.8 indicates high level of agreement between assessors, a value between 0.61 and 0.8 a substantial agreement, a value between 0.41 and 0.6 a moderate level of agreement, and a value of < 0.41 poor level of agreement [31]. SPSS 20.0 was used to calculate K values.

The main dependent outcome variable was running-induced leg injury. Identified risk factors were summarized per injury, overall and injury specific. All risk factors were grouped into three main categories: 1) personal factors, 2) running/training related factors, and 3) health & lifestyle related factors.

To evaluate associations between risk factors and running injuries p-values, crude odds ratios (ORs), hazard ratios (HRs,) and relative risks (RRs) with 95% confidence intervals (CI) were retrieved from the included publications. Crude values were used for this evaluation to prevent biases and shortcomings of stepwise multiple regression analyses [23]. Adjusted risk estimates derived from multivariable regression analyses were only used when the independent variables of the model were pre-specified and not based on a stepwise selection algorithm or when crude associations were not available.

Pooling and Best-Evidence Synthesis

Separate meta-analyses with the random effects model [32] were planned to obtain the pooled OR, HR or pooled RR (with 95% CI) for running injuries. If pooling was not possible due to heterogeneity of the study populations, a best evidence synthesis was presented.

For each identified risk factor, levels of evidence were established for the association between this factor and the occurrence of running injuries. These levels of evidence were based on the guidelines of van Tulder et al. [33] and were divided into the following levels: strong evidence, defined as consistent findings (in ≥75% of the studies) in multiple (≥2) high-quality studies; moderate evidence, defined as consistent findings (in ≥75% of the studies) in one high-quality study and multiple low-quality studies; limited evidence, defined as consistent findings (in 75% of the studies) in multiple low-quality studies or one high-quality study; and conflicting evidence, defined as conflicting findings reported by <75% of the studies reporting consistent findings.

Sex Ratio

In studies in which risk factors were presented separately for men and women, possible sex differences in risk were determined by dividing the risk factor for women by the risk factor for men, which produced a sex ratio. A ratio higher than 1.25 (i.e., women had a higher risk) or lower than 0.75 (i.e. women had a lower risk) was regarded as a relevant sex difference [34,35].

Results

Literature Search

A flow chart for article retrieval is given in Figuur 1. Of 400 articles retrieved as potentially relevant, 17 were considered eligible for full-text screening based on title and abstract. Of these 17 studies, 2 [36,37] seemed, after consultation with the authors, to have an abstract only, so 15 articles were included for quality assessment, data extraction, and analysis.

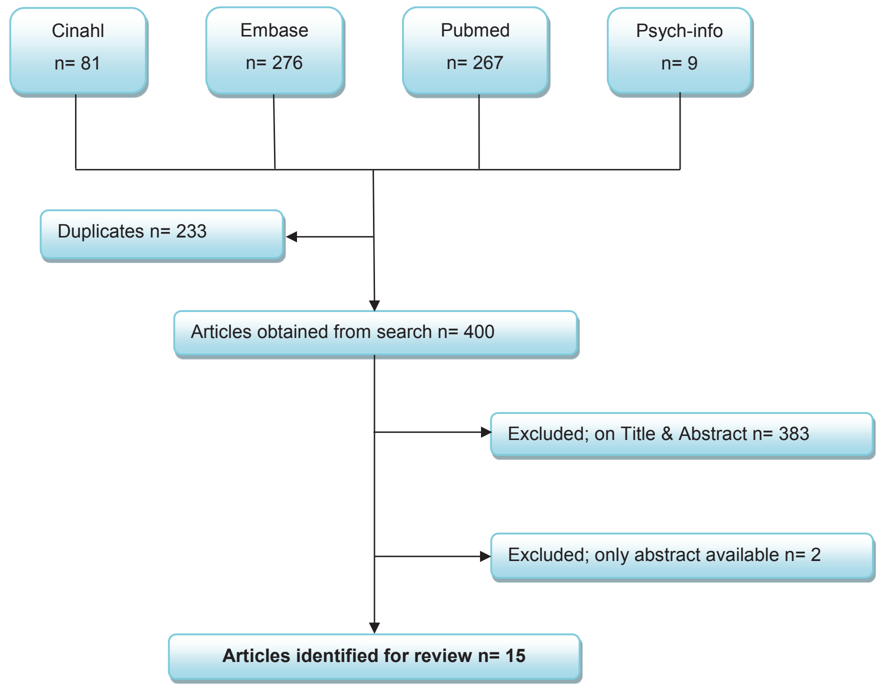

Figure 1. Flow Chart of the search process of articles

Included Studies

Of the 15 included longitudinal cohort studies, 13 were prospective [10,17,22,24,38–46] and 2 retrospective [9,47] studies. They were all published in English. The follow-up time of these studies ranged from 8 weeks to 1 year and the mean age of study participants ranged from 36 to 44 years. Thirteen studies had a mixed population, 1 study included only women [39], 1 study included only men [42], and 1 study did not report the sex of the study population [47]. BMI and height differed between the various reports. In the study of Bennett et al. [38], 13.6% of study participants had a low BMI (<18.5 kg/m^2); the studies of Lun et al. [44] and McKean et al. [47] did not report BMI, weight, or height. The proportion of subject analyzed in the original studies ranged from 46% to 100%. Seven studies [10,22,24,39–41,43] included novice runners. All studies used different (running) definitions of injury, except for one research group who used the same definition in their two studies [9,10,17,22]. Five studies defined running-related injuries as involving the lower limb [38,40,41,43,46], 4 studies included the influence of the symptoms on running [9,17,24,47], and 6 studies defined injuries in terms of the lower limb and the influence of symptoms [10,22,39,42,44,45]. Two studies included a specific time frame of running restriction caused by the running injury [10,22]. Four studies specifically looked at signs and symptoms related to Achilles tendinopathy [41,46] and patellofemoral dysfunction/ pain syndrome [39,43]. Only Bennett et al. [38] excluded traumatic injuries. Wen et al. [9,17] included overuse injuries in their definition of injury. Wen et al. [9,17] investigated the same experienced runners in a retrospective study [9] and in a longitudinal prospective study, published a year later [17]. In order to avoid duplication, the results of these two studies were considered as coming from one study population [48]. The incidence of the running injuries reported in the included studies where in the range of 20.6% to 79.3%, 25.0% to 79.5% and 19.8% to 79.1% for overall, men and women, respectively. The injury specific incidences were 7.8% and 14.3% for Achilles tendinopathy injuries [41,46] and 16.7% and 20.8% for patellofemoral pain injuries [39,43]. Table 2 presents a summary of these studies including the population characteristics (age, sex, BMI, and the proportion of people analyzed), type of running, injury definition and (running) incidence; injury specific and/or overall and, if given, sex specific.

Risk of Bias

The overall agreement between the two reviewers was 77% with a moderate reliability (Kappa = 0.6). The agreement for the individual items ranged from 53% (item 12) to 100% (item 6).Most disagreement was seen for item 5 ("Were the data on system factors, running/training related factors, and/or health and lifestyle factors collected using standardized methods of acceptable quality?"), item 7 ("Were the data on outcome collected using standardized methods of acceptable quality?"), and item 12 ("Positive, if the number of cases in the final multivariable was at least ten times the number of independent variables in the analysis."), because of the different interpretation of the definitions of "standardized methods", "acceptable quality", and by miscalculating/interpretation of the number of cases in the final multivariable, respectively. Other disagreements were mostly due to differences in interpretation. All disagreements were resolved in a consensus meeting. Nine of the 13 prospective cohort studies [10,17,22,24,38,42,44–46] were considered to be high quality (> 6 items positive), as were the 2 retrospective cohort studies [9,47] (Table 3).

Risk Factors for Running Injuries; Overall and Injury Specific

The heterogeneity in study populations, in operationalization of both outcomes and risk factors, and time to follow-up prevented us from following a formal meta-analytical approach. Study populations varied from novice runners to recreational runner and competitive runners, outcomes from running-related injuries, overall injuries to lower leg overuse injuries and more localized injuries, e.g. Achilles Tendinopathy, back injuries (Tables 4–6). Follow-up time points varied from 8 weeks to 1 year (Table 2). Across the studies different categories of independent variables were used with different cut-off points (Tables 4–6) or injured versus injured runners were compared using continuous values of risk factors (e.g. the mean age of injured runners was higher than the mean age of non-injured runners [46]). For these reasons we refrained from doing a meta-analysis. We therefore choose to present the results using a best evidence synthesis. Risk factors were divided into three categories: personal factors, running/ training related factors and health and lifestyle factors (see Tables 4–6).

Table 2. Study Characteristics

Author, year of publication	Study design, size and follow up period	Population characteristics: Age (yr) (mean ± sd)	Sex (%)	BMI (kg/m2)	No included/ analyzed (%)	Running type	Injury definition	Incidence (%)
Bennett et al., 2012 [38]	Prospective cohort, n=77 Cross-country season	N.F.	M: 52.5 W: 47.5	13.6% <18.5	77/59 (77%)	Cross-country athletes	Exercise-related leg pain: pain located in the anterior, medial, posterior, or lateral leg not associated with a traumatic injury.	Overall: 44.1 M; 41.9 W: 46.4
Hirschmüller et al., 2012 [46]	Prospective cohort, n=634 1 year	43.2 ± 11.0 (range 19 - 74)	M: 66.7 W: 33.3	23.0 ± 2.0 (range 16.0 – 35.8)	634/427 (67%)	Runners from 23 national running events	Midportion Achilles tendinopathy: pain localized 2-6 cm proximal to the insertion and at least two of the following minor criteria reported: palpable thickening of the tendon, tenderness of the Achilles tendon, or Achilles tendon pain at the beginning of physical activity.	Injury specific: 14.3
Thijs et al., 2011 [39]	Prospective cohort, n=77 10 weeks	38 ± 9	W: 100	24.6 ± 2.9	77/77 (100%)	Female novice recreational runners	Patellofemoral dysfunction syndrome: Characteristic history and symptoms involved retropatellar pain: typically dull and diffuse around the patellofemoral joint, during and/or after activities such as running, squatting, kneeling, going up and down stairs, cycling, prolonged sitting with the knee in flexion, or rising from a seated position. Other symptoms involved stiffness and swelling, giving way, and crepitus at the knee. On clinical assessment, the participants had to exhibit two of the following clinical criteria: (1) pain while compressing the patella against the femoral condyles with the knee in full extension (2) tenderness of the medial and/or lateral posterior surface of the patella on palpation (3) a painful resisted knee extension and/or (4) pain at the patellofemoral joint when isometrically contracting	Injury specific: 20.8

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							the quadriceps muscle against suprapatellar resistance with the knee in 15o of flexion.	
Buist et al., 2010 [10]	Prospective cohort, n=875 8 weeks	43.7 ± 9.5 M: 46.5 ± 9.4 F: 42.3 ± 9.2	M: 32.9 W: 67.1	24.9 ± 3.3 M: 25.9 ± 3.2 F: 24.4 ± 3.2	875/629 (72%)	Novice and recreational runners	Running-related injury: any musculoskeletal pain of the lower limb or back causing a restriction in running (mileage, pace or duration) for at least 1 day.	Overall: 25.9 M: 31.4 W: 23.2
Buist et al., 2010 [22]	Prospective cohort, n=532 8 or 13 weeks	M: 42.3 ± 9.9 F: 37.9 ± 9.9	M: 42.5 W: 57.5	M: 25.9 ± 3.3 F: 24.2 ± 3.4	532/532 (100%)	Novice runners	Running-related injury: running-related musculoskeletal pain of the lower extremity or back causing a restriction of running for at least 1 week, that is, 3 scheduled consecutive training sessions.	Overall: 20.6
Hesar et al., 2009 [40]	Prospective cohort, n=131 10 weeks	39.09 ± 10.3	M: 15.3 W: 84.7	Weight (kg): 70.33 ± 11.31 Height (cm): 168.47 ± 7.77	131/131 (100%)	Novice runners	Lower leg overuse injuries	Overall: 20.6 M: 25.0 W: 19.8
Van Ginckel et al., 2009 [41]	Prospective cohort, n= 129 10 weeks	39 ± 10	M: 14.7 W: 85.3	24.8 ± 3.5	129/63 (49%)	Novice runners	Achilles Tendinopathy: an insidious, gradual onset of mid-portion pain, palpated tenderness along the tendon, (morning) stiffness, tenderness and pain on exertion.	Overall: 53.5 Injury specific: 7.8
Van Middelkoop et al., 2008 [42]	Prospective cohort, n= 1500 1 month	43.8 ± 9.6	M: 100	23.5 ± 2.1 BMI > 25: 15.1%	1500/694 (46%)	Recreational/ amateur runners	Running injury: a self-reported ''injury on muscles, joints, tendons and/or bones of the lower extremities (hip, groin, thigh, knee, lower leg, ankle foot and toe) that the participant attributed to running''. The problem had to be severe enough to cause a reduction in the distance, speed, duration or frequency of running.	Overall: 28.1
Thijs et al., 2008 [43]	Prospective cohort, n= 129 10 weeks	37 ± 9.5	M: 12.7 W: 87.3	25 ± 3	129/102 (79%)	Novice recreational runners	Patellofemoral pain (PFP): a characteristic history and symptoms of PFP syndrome and exhibit two of the following criteria on assessment: pain on direct compression of the patella against the femoral condyles with the knee in full extension; tenderness of the posterior surface of the lateral or medial rim of the patella on palpation; pain on	Injury specific: 16.7

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Tabel 2 Contd

							resisted knee extension; or pain with isometric quadriceps muscle contraction against suprapatellar resistance with the knee in 15° of flexion. In addition, subjects had to have negative findings in the examination of knee ligaments, menisci, bursae, synovial plicae, Hoffa's fat pad, iliotibial band, the hamstrings, quadriceps and patellar tendons and their insertions.	
McKean et al., 2006 [47]	Retrospective survey, n=2886 1 year	> 40 years: 34%	N.F.	N.F.	2886/2886 (100%)	Runners participating in Hood to Coast Relay	Running injury: an event that affected the athlete's ability to train or race over the previous year.	Overall: 46.3
Lun et al., 2004 [44]	Prospective cohort, n=153 6 months	38.0	M: 50.6 W: 49.4	N.F.	153/87 (57%)	Recreational runners	Lower limb injury: any musculoskeletal symptom of the lower limb that required a reduction or stoppage of normal training.	Overall: 79.3 M: 79.5 W: 79.1
Taunton et al., 2003 [24]	Prospective cohort, n= 844 13 weeks	M: 12.3% <30, 51.5% 31 – 49, 19.1% 50 – 55, 17.2% >56. F: 18.6% <30, 63.6% 31 – 49, 11.5% 50 – 55, 6.3% >56.	M: 24.4 W: 75.6	M: 1.0% <19, 55.1% 20 – 26, 41.0% >26. F: 4.3% <19, 69.8% 20 – 26, 16.7% > 26.	844/840 (100%)	Recreational runners interested in either completing the 10 km race distance (novice runners) or improving their race time (intermediate runners).	Injury: 1, pain only after exercise; 2, pain during exercise, but not restricting distance or speed; 3, pain during exercise and restricting distance and speed; 4, pain preventing all running. A runner was classified as being injured if they experienced at least a grade 1 injury (pain only after exercise). Diagnoses from participants that did not consult a qualified doctor or physiotherapist were not included.	Overall: 29.5
Wen et al., 1998 [17]	Prospective cohort, n= 355 32 weeks	41.8 ± 10.8	M: 42.0 W: 58.0	M: Weight (kg): 79.3 ± 11.7 Height (cm): 176.8 ± 6.3 F: Weight (kg):	355/255 (72%)	Runners participating in a training program for a marathon	Running injury: answering yes to having had 'injury or pain' to an anatomical part; answering yes to having had to stop training, slow pace, stop intervals, or otherwise having had to modify training; and a 'gradual' versus 'immediate' onset	Overall: 35.3

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				64.1 ± 12.3 Height (cm): 164.3 ± 7.3			of the injury or a self-reported diagnosis that is generally considered an overuse injury.	
Wen et al., 1997 [9]	Retrospective cohort, n= 355 12 months	41.1 ± 10.6 (range: 21 - 78)	M: 43.8 W: 56.2	M: Weight (kg): 81.0 ± 13.4 (range: 59 – 128) Height (cm): 177.3 ± 6.8 (range: 163 – 193) F: Weight (kg): 64.0 ± 13.4 (range: 43 – 146) Height (cm): 164.3 ± 7.3 (range: 150 - 183)	355/304 (86%)	Experienced runners enrolling in a marathon training program	Running injury: subject answered "yes" to having had "injury or pain" to that anatomic part; and answered "yes" to having had to stop training, or to have to slow pace, stop intervals, or otherwise to have had to modify training; and the onset of the injury was "gradual" (versus "immediate"), or his or her diagnosis (self-reported) was one that is generally considered an overuse injury.	Overall: 44.7
Macera et al., 1989 [45]	Prospective cohort, n= 966 12 months	M: 41.6 ± 9.5 (range: 13 – 75) F: 36.1 ± 8.2 (range: 22 – 64)	M: 83.2 W: 16.8	M: 23.0 ± 2.2 (range: 16.5 – 31.0) F: 25.8 ± 2.4 (range: 20.2 – 34.6)	966/583 (60%)	Habitual runners	Running-related lower-extremity injury: A self-reported ''muscle, joint or bone problem/injury'' of the lower extremities (foot, ankle, Achilles tendon, calf, shin, knee, thigh, or hip) that the participant attributed to running. The problem had to be severe enough to cause a reduction in weekly distance, a visit to a health professional, or the use of medication.	Overall: 51.5 M: 52.0 W: 49.0

NF, not found: BMI, body mass index: W, women: M, men

Table 3. Results of the risk of bias assessment

		1	2	3	4	5	6	7	8	9	10	11	12	Total score (n)	Total score (%)
1	Bennett et al., 2012 [38]	+	-	+	+	+	-	-	+	+	-	+	-	7	58
2	Hirschmüller et al., 2012 [46]	+	?	-	+	+	+	-	+	+	-	+	+	8	67
3	Thijs et al., 2011 [39]	+	?	+	+	+	-	+	-	+	-	-	-	6	50
4	Buist et al., 2010 [10]	+	-	-	+	+	-	-	+	+	+	+	+	8	67
5	Buist et al., 2010 [22]	+	+	+	+	+	-	-	+	+	+	+	?	9	75
6	Hesar et al., 2009 [40]	+	?	+	+	+	-	?	+	+	-	-	-	6	50
7	Van Ginckel et al., 2009 [41]	+	?	-	+	+	-	?	+	+	-	+	-	5	42
8	Van Middelkoop et al., 2008 [42]	+	-	+	+	+	-	-	+	+	+	+	+	9	75
9	Thijs et al., 2008 [43]	+	?	-	+	+	-	+	-	+	-	-	-	5	42
10	McKean et al., 2006 [47]	+	-	+	+	+	-	+	+	+	+	+	+	10	83
11	Lun et al., 2004 [44]	+	?	+	+	+	-	-	-	+	+	+	-	7	58
12	Taunton et al., 2003 [24]	+	+	+	-	+	-	+	+	+	+	+	+	10	83
13	Wen et al., 1998 [17]	+	-	+	+	+	-	-	+	+	+	+	+	9	75
14	Wen et al., 1997 [9]	+	-	+	+	+	+	-	-	+	+	-	-	7	58
15	Macera et al., 1989 [45]	+	-	?	+	+	+	-	+	+	+	+	-	8	67

+ Well-described and well-performed item; - item was described but not well performed; ? item was unclear due to insufficient available information.

Personal Factors; Table 4

Sex. One low quality study [40] and five high quality studies [10,22,38,46,47] assessed sex as risk factor for running injuries. One high-quality studies [22] found men to have a significantly higher risk of running-related injuries than women, and particularly younger men (< 40 years) [47]. Thus there was limited evidence that men are at higher risk of running-related injuries.

Age. Four low-quality studies [39–41,43] and four high-quality studies [9,17,44,46] investigated the relationship between age and running injuries. Only one study found age to have a significant effect on running injuries: Wen et al. [17] showed that lower age was significantly protective against overall (not specified) overuse injury. Thus there was only limited evidence that lower age affects the risk of running-related injuries. Wen et al. [9] and Hirschmüller et al. [46] found higher age to be a significant risk factor for hamstrings injuries and midportion Achilles tendinopathy, respectively. This indicates that there is limited evidence that age affects the risk of hamstrings injuries and midportion Achilles tendinopathy.

BMI. Three low-quality studies [39,41,43] and three high-quality studies [9,38,46] examined BMI as a risk factor for running injuries. BMI was not found to have significant effect on injury risk in runners overall, but Wen et al. [9] found a higher BMI to be a risk factor for back injuries in women and a lower BMI to be a risk factor for foot injuries in men. Thus there was limited evidence that BMI is a risk factor for back injuries in women and for foot injuries in men.

Height. Four low-quality studies [39–41,43] and three high-quality studies [9,17,46] investigated height as a risk factor for running injuries. Wen et al. [9] found lower height in men to be a significant risk factor for foot injuries, indicating limited evidence. Weight. Three low quality studies [39–41,43] and three high-quality [9,17,46] study investigated weight as a risk factor for running injuries. Wen et al. [9] found higher weight in women and lower weight men to be a risk factor for back injuries and foot injuries, respectively. In the same research group, Wen et al. [17] found higher weight to be protective against foot injuries. Thus there was limited evidence that higher weight in women and lower weight in men were risk factors for back and foot injuries, respectively. Furthermore, there was limited evidence that a heavier weight protects against foot injuries.

Navicular drop. One high-quality study [38] investigated the influence of navicular drop on running injuries. Bennett et al. [38] found runners with a high navicular drop (>10 mm) in the left or right foot were at greater risk for medial exercise-related leg pain. Also, a navicular drop of more than 10 mm in only the left foot was significantly associated with a higher risk of medial exercise-related leg pain. Thus there was limited evidence that navicular drop (> 10 mm) is a risk factor for running injuries.

Intratendinous blood flow. Only one high-quality study [46] investigated the influence of blood flow in the Achilles tendon on Achilles tendinopathy in runners. Runners with intratendinous microvessels (indicating primary neovascularization) were at greater risk of mid-portion Achilles tendinopathy. Thus there was limited

Table 4. Significant personal risk- & protective factors for running injuries

Independent variable	MQ	Author	Injury	Specification of independent variable	Outcome (95% CI)
Sex	HQ	Buist et al., 2010 [22]	Running-related injury (RRI)	M, 42.5%	HR= 1.5 (P = 0.04)
	HQ	McKean et al., 2006 [47]	Running injury	M < 40 yrs.	OR= 1.28 (1.06 – 1.54)†
Age	HQ	Wen et al., 1998 [17]	Overall injuries	Lower age (group: miles)‡	RR= 0.39 (0.15 – 0.97)†
	HQ	Wen et al., 1997 [9]	Hamstrings injuries	Higher age	P= 0.019
	HQ	Hirschmüller et al., 2012 [46]	Midportion Achilles tendinopathy (MPT)	Higher age	P< 0.05
BMI	HQ	Wen et al., 1997 [9]	Back injuries	Higher BMI (women)	P= 0.009
			Foot injuries	Lower BMI (men)	P= 0.045
Height	HQ	Wen et al., 1997 [9]	Foot injuries	Shorter height (men)	P= 0.033
Weight	HQ	Wen et al., 1997 [9]	Back injuries	Higher weight (women)	P= 0.002
			Foot injuries	Lower weight (men)	P= 0.011
	HQ	Wen et al., 1998 [17]	Foot injuries	Higher weight§	RR= 0.94 (0.89 – 0.99)†
Navicular drop (ND)	HQ	Bennett et al., 2012 [38]	Medial exercise-related leg pain (ERLP)	Left ND >10 mm (hyperpronation)	OR= 5.3 (1.2- 22.9)
				Right or left ND >10 mm (hyperpronation)	OR= 4.4 (1.0- 18.9)
Intratendinous blood flow	HQ	Hirschmüller et al., 2012 [46]	Midportion Achilles tendinopathy (MPT)	Neovascularization I°	OR= 6.9 (2.6 – 18.8)†
Mediolateral force ratios	LQ	Hesar et al., 2009 [40]	Lower leg overuse injuries (LLOI)	First metatarsal contact; ratio 1	OR= 0.63 (0.42- 0.95)
				First metatarsal contact; ratio 2	OR= 0.64 (0.42- 0.96)
				First metatarsal contact; ratio 3	OR= 0.63 (0.42- 0.95)
				First metatarsal contact ratio 8	OR= 0.58 (0.38- 0.89)
				Forefoot flat; ratio 1	OR= 0.63 (0.41- 0.98)
				Forefoot flat; ratio 3	OR= 0.62 (0.40- 0.96)

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				Initial contact phase ratio 8	OR= 0.62 (0.39- 1.00)
	LQ	Van Ginckel et al., 2009 [41]	Achilles Tendinopathy (AT)	Forefoot flat; ratio 2	P= 0.009
				Less force ratios at foot flat phase ratio 2	P = 0.045
Mediolateral displacement of the centre of force	LQ	Hesar et al., 2009 [40]	Lower leg overuse injuries (LLOI)	x-comp heel off	OR= 0.76 (0.64- 0.92)
				x-comp forefoot contact phase	OR= 0.41 (0.23- 0.74)
				x-comp foot flat phase	OR= 0.58 (0.38- 0.90)
				x-comp forefoot push-off phase	OR= 1.64 (1.07- 2.51)
Velocity mediolateral displacement of the centre of force	LQ	Hesar et al., 2009 [40]	Lower leg overuse injuries (LLOI)	Forefoot flat	OR= 0.50 (0.27- 0.92)
Anteroposterior displacement of the centre of force	LQ	Hesar et al., 2009 [40]	Lower leg overuse injuries (LLOI)	Forefoot flat	OR= 1.47 (1.12- 2.77)
	LQ	Van Ginckel et al., 2009 [41]	Achilles Tendinopathy (AT)	Total displacement (mm)	P= 0.007
				Less displacement at last foot contact (mm)	P = 0.008
				Less displacement during forefoot push off phase (mm)	P = 0.033
Absolute force-time integral underneath metatarsal heads	LQ	Hesar et al., 2009 [40]	Lower leg overuse injuries (LLOI)	Metatarsal head 5	OR= 1.72 (1.13- 2.61)
Vertical peak force underneath foot	LQ	Hesar et al., 2009 [40]	Lower leg overuse injuries (LLOI)	Metatarsal head 5	OR= 1.66 (1.08- 2.54)
	LQ	Thijs et al., 2008 [43]	Patellofemoral pain (PFP)	Higher force underneath metatarsal head 2	P= 0.016
				Higher force underneath metatarsal head 3	P= 0.026
				Higher force underneath lateral heel	P= 0.034
Time to peak force	LQ	Van Ginckel et al., 2009 [41]	Achilles Tendinopathy (AT)	At medial heel – less seconds	P = 0.032
Time to vertical peak force relative to time of foot contact	LQ	Thijs et al., 2008 [43]	Patellofemoral pain (PFP)	Less time at medial heel	P= 0.016
				Less time at lateral heel	P= 0.037
Alignment measurements	HQ	Wen et al., 1998 [17]	Overall injuries	Low leg length difference (group: hours)‡	RR= 1.96 (1.07 – 3.58)†

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Tabel 4 Contd

			Higher combined arch index (group: hours)‡	RR= 0.0 (0.0 – 0.37)†
		Knee injuries	Low heel valgus (group: miles)‡	RR= 0.08 (0.01 – 0.74)†
			High heel valgus (group: miles)‡	RR= 0.09 (0.01 – 0.81)†
			Higher right arch index (group: hours)‡	RR= 0.11 (0.01 – 0.90)†
		Shin injuries	High left tubercle-sulcus angle (group: miles)‡	RR= 11.02 (2.00 – 60.86)†
			Higher knee varus (group: miles)‡	RR= 1.09 (1.03 – 1.15)†
		Foot injuries	Higher heel valgus (group: miles)‡	RR= 0.76 (0.58 – 0.98)†
			Higher heel valgus (group: hours)‡	RR= 0.74 (0.58 – 0.94)†
HQ	Wen et al., 1997 [9]	Ankle injuries	Lowest left tubercle-sulcus angle	P = 0.02
			Lowest combined tubercle-sulcus angle	P= 0.049

† Represents adjusted OR, HR or RR

§ RRs were calculated dividing the number of injured runners by the total number of runner-weeks accumulated (relative incidence ratios) (n = 255)

‡ RRs were obtained from special subgroups in which information on distances run (miles) and time spent running (hours) was measured (total n = 108)

M, men: BMI, Body mass index: ND, Navicular drop: CI, Confidence interval: OR, Odds ratio: HR, Hazard ratio: RR, Relative risk: MQ, Methodological quality:

HQ, High quality: LQ, Low quality

evidence that impaired intratendinous blood flow is a risk factor for running injuries.

Force distribution pattern. Three low-quality studies [40,41,43] investigated force distribution patterns in relation to running injuries. Hesar et al. [40] found significantly less laterally directed force distribution at first metatarsal contact and forefoot flat, and significantly more medial directed force displacement in the forefoot contact phase, foot flat phase, and heel-off phase in runners without lower leg overuse injuries. These individuals also had a significantly quicker change in the center of force (COF) at forefoot flat, a lower force and loading underneath the lateral border of the foot, and a significantly lower directed force displacement of the COF at forefoot flat than did runners with lower leg injuries. Van Ginkel et al. [41] found a significant decrease in the total posterior–anterior displacement of the COF and a laterally directed force distribution underneath the forefoot at 'forefoot flat' as intrinsic gait-related risk factors for Achilles tendinopathy in novice runners. Thijs et al. [43] demonstrated that runners with a significantly higher vertical peak force underneath the second metatarsal and shorter time to the vertical peak force underneath the lateral heel were at higher risk for patellofemoral pain syndrome. In conclusion, there was limited evidence that a number of force distribution factors/patterns are risk factors for, or protective against, lower leg injuries, Achilles tendinopathy, and patellofemoral pain in runners [40,41,43].

Alignment. Three high-quality studies [9,17,44] investigated the influence of alignment on the occurrence of running injuries. In their prospective study, Wen et al. [17] found that runners in the group with the highest combined arch index were protective against, and runners in the group with the lowest leg difference were at higher risk for running injuries, respectively. In the retrospective study by the same research group [9], runners in the groups with the lowest left tubercle-sulcus angle and lowest combined (mean left and right) tubercle-sulcus angle were found to be at higher risk for ankle injuries. Runners in the groups with the lowest heel valgus, the highest heel valgus, and highest right arch index were found to be protective against knee injuries [17]. In this same prospective study, runners in the group with the highest left tubercle- sulcus angle and highest knee valgus were found to be significant at risk for shin injuries [17]. In subgroup analyses of this study, the highest heel valgus group was significant protective against foot injuries (expressed as injury incidence per 1000 miles running, or as injury incidence per 1000 hours running) [17]. In conclusion, there was limited evidence that a small difference in leg length is a risk factor for overall running injuries. There was also limited evidence that a large left tubercle-sulcus angle and a large knee varus are risk factors for shin injuries. Furthermore there was limited evidence that a low left tubercle-sulcus angle and combined (average of left and right) tubercle-sulcus angle are risk factors for ankle injuries and that several alignment factors are protective against running injuries.

Running & Training Related Factors for Running Injuries; Table 5

Running experience. Five high-quality studies investigated the relationship between running experience and running injuries [9,17,42,46,47]. Limited evidence was found that more running experience was a risk factor for overall running injuries [17]. There was also limited evidence that running with less (< 1 year) experience was protective for running injuries [47]. Limited evidence was found that more running experience was a risk factor for knee [42] and foot injuries [17].

Training. Five high-quality studies investigated the relationship between training factors and running injuries [9,17,42,46,47]. The prospective study of Wen et al. [17] found increased hours of running per week to be protective against overall injuries (expressed in terms of incidence per mileage or hours run). There was limited evidence that age < 40 years combined with running ≥ 6 times a week was a significant risk factor for running injury [47], as there was for age ≥ 40 years combined with running ≥ 6 times a week [47]. There was also limited evidence that age < 40 years combined with running 1–3 times a week and running < 10 miles per week were significant protective factors for running injury [47], and an age ≥ 40 years combined with running 1–3 times a week was protective [47].

Van Middelkoop et al. [42] found that interval training was protective against knee injury in men. In contrast, the two high quality studies by Wen et al. [9,17] found more interval training to be a risk factor for shin injuries. The evidence for interval training being a risk or protective factor was limited. There was also limited evidence that increasing hours of running per week is protective against knee and foot injuries [17] and that a slower training pace was a risk factor for heel injuries [9].

Surface. Only one high-quality study [9] investigated the relationship between surface and running injuries. There was limited evidence that running time on concrete surface is protective against back and thigh injuries [9].

Distance. Four high-quality studies [9,42,44,46] analyzed running distance as independent variable for running injuries. There was limited evidence that higher weekly mileage is associated with hip and hamstrings injuries [9] and that a training distance of 0–40 km a week is protective against the incidence of calf injuries [42].

Race participation. One high-quality study [42] (= limited evidence) found the risk of running injuries to be higher in men who had participated in more than six races in the last year.

Shoe use. Two high-quality studies [9,17] analyzed the relationship between shoe use and running injuries. There was limited evidence that changing shoes more frequently was a risk factor for overall injuries [9] and limited evidence for using one pair of running shoes or alternating between two pairs versus alternating between more than two pairs of shoes as a risk factor for knee injuries [9]. Furthermore, limited evidence was found for a higher number of shoes as a risk factor for shin injuries [17].

Health & Life-Factors Related for Running Injuries; Table 6

History of previous injury. Four high-quality studies [17,38,42,46] investigated the relationship between running injuries and previous injuries. Bennett et al. [38] found that runners with a history of exercise-related leg pain for a month or a year were at greater risk of a relapse of exercise- related leg pain. Wen et al. [17] also found previous injuries to be a risk factor for running injuries. In the high-quality study of

Table 5. Significant running/training-related risk factors for running injuries

Independent variable	MQ	Author	Injury	Specification of independent variable	Outcome (95% CI)
Running experience	HQ	McKean et al., 2006 [47]	Running injury	< 40 yrs group: Running less than 1 year (↓ risk)	P= 0.01
	HQ	Wen et al., 1998 [17]	Overall injuries	Greater experience§	RR= 1.88 (1.16 – 3.05)†
			Foot injuries	Greater experience§	RR= 1.09 (1.03 – 1.15)†
	HQ	Van Middelkoop et al., 2008 [42]	Incident knee injury	Running experience; 15+ years	OR= 2.56 (1.22 – 5.34)†
	HQ	McKean et al., 2006 [47]	Running injury	< 40 yrs group	
				• 6+ runs p/w	P< 0.05
				• 1- 3 runs p/w (↓ risk)	P< 0.05
				• Running < 10 miles per week (↓ risk)	P< 0.05
				≥ 40 yrs group	
				• 6+ runs p/w	P= 0.01
				• 1- 3 runs p/w (↓ risk)	P= 0.001
	HQ	Wen et al., 1998 [17]	Overall injuries	Increased hours/week (group: miles)‡	RR= 0.57 (0.42 – 0.78)†
				Increased hours/week (group: hours)‡	RR= 0.58 (0.45 – 0.73)†
				Increased miles/week (group: miles)‡	RR= 0.90 (0.82 – 0.99)†
			Knee injuries	Increased miles/week (group: miles)‡	RR= 0.90 (0.82 – 0.99)†
				Increased hours/week (group: hours)‡	RR= 0.49 (0.30 – 0.80)†
			Foot injuries	Increased hours/week (group: miles)‡	RR= 0.31 (0.15 – 0.63)†
				Increased hours/week (group: hours)‡	RR= 0.21 (0.10– 0.44)†
			Shin injuries	More intervals§	RR= 14.89 (0.50 – 147.33)†
	HQ	Van Middelkoop et al., 2008 [42]	Knee injury	M, 100%: Interval (always)	OR= 0.49 (0.26 – 0.93)†
	HQ	Wen et al., 1997 [9]	Shin injuries	Higher proportion of intervals	P= 0.04
			Heel injuries	Slower pace	P= 0.034

Continued next page

Tabel 5 Contd

Surface	HQ	Wen et al., 1997 [9]	Back injuries	Lower percentage training on concrete/asphalt	P= 0.005
			Thigh injuries	Lower percentage training on concrete/asphalt	P= 0.011
Distance	HQ	Van Middelkoop et al., 2008 [42]	Incident calf injury	M, 100%: Training distance 0 – 40 km	OR= 0.36 (0.17 – 0.78)†
	HQ	Wen et al., 1997 [9]	Hip injuries	More miles per week	P= 0.035
			Hamstring injuries	More miles per week	P= 0.01
Race participation	HQ	Van Middelkoop et al., 2008 [42]	Running injury	M, 100%: Race participation last year: > 7x	OR= 1.55 (1.02- 2.36)
Shoe use	HQ	Wen et al., 1997 [9]	Overall injuries	Changing shoes sooner	P= 0.016
			Knee injuries	One pair and alternating between 2 pairs	P= 0.037
	HQ	Wen et al., 1998 [17]	Shin injuries	Higher number of shoes	RR= 6.91 (1.36 – 35.15)†

† Represents ratios of adjusted OR, HR or RR

§ RRs were calculated dividing the number of injured runners by the total number of runner-weeks accumulated (relative incidence ratios)

‡ RRs were obtained from special subgroups in which information on distances run (miles) and time spent running (hours) was measured

M, Men:: CI, Confidence interval: OR, Odds ratio: ↓ risk, Lower Risk: HR, Hazard ratio: RR, Relative risk: MQ, Methodological quality: HQ, High quality

Van Middelkoop et al. [42], lower extremity injury in the previous 12 months was found to be a risk factor for running injury in men. In conclusion, there was strong evidence that previous injury is a risk factor for running injuries.

Van Middelkoop et al. [42] found that a lower extremity injury in the previous 12 months was a risk factor for a knee injury, and that an injury at another location (hip, groin, thigh, knee, ankle, or/and foot) was a risk factor for calf injury. None of the other studies identified risk factors for knee and/or calf injury. Bennett et al. [38] found that runners with a history of medial exercise-related leg pain lasting longer than 1 month were at greater risk of medial exercise-related leg pain. A history of old shin injuries was found to be a risk factor for shin injuries in one high-quality study [17]. A previous disorder of the Achilles tendon was a significant risk factor for midportion Achilles tendinopathy in one high-quality study [46]. In conclusion, there was limited evidence that previous injury is a risk factor for specific running injuries, namely, medial exercise-related leg pain, midportion Achilles tendinopathy, shin injuries, knee and calf injuries.

Orthotic/inserts. Two high-quality studies [9,47] investigated orthotic/inserts as a risk factor for running injuries. Both found wearing orthotics or using shoe inserts to be a risk factor for running injuries (moderate evidence). Wen et al. [9] found the use of shoe insert to be a risk factor for foot injuries, indicating limited evidence for this association.

Sex Ratio. Five high-quality studies [10,22,24,45,47] analyzed data for men and women separately (see Table 7). One study showed women to be at significantly lower risk of injuries overall than men [22]. Two studies showed men with a history of injury were at higher risk of running injuries than women with a similar history [22,45]. One high-quality study found the risk of injury to be higher in women than men if the women were older [10], had previously engaged in other sports activities [10], had the previous year participated in a marathon [45], had a weekly distance running of 48–63.8 km for the preceding 3 months [45], ran on concrete surface [45], and had running shoes that were 4- to 6-months old [24], with sex ratios of 1.4, 1.9, 2.0, 2.2, 4.2, and 4.9, respectively. Men were, in comparison with women, at greater risk of injury if they restarted running [10], had less than 2 years' running experience [45], had a weekly running distance of 32–47.8 km [45] or had a weekly running distance > 64 km [45], with a sex ratio of 0.7, 0.7, 0.7 and 0.4, respectively.

Table 6. Significant health & lifestyle factors related for running injuries

Independent variable	MQ	Author	Injury	Specification of independent variable	Outcome (95% CI)
History of previous injuries	HQ	Bennett et al., 2012 [38]	Exercise-related leg pain (ERLP)	ERLP history (year)	OR= 18.4 (2.2- 152.7)
				ERLP history (month)	OR= 8.5 (2.6- 28.2)
			Medial exercise-related leg pain (ERLP)	Medial ERLP history (month)	OR= 5.9 (1.4- 25.3)
	HQ	Hirschmüller et al., 2012 [46]	Midportion Achilles tendinopathy (MPT)	Prev. disorders of the Achilles tendon	OR= 3.8 (1.7 – 8.5)†
	HQ	Van Middelkoop et al., 2008 [42]	Running injury	M, 100%: Injury previous 12 months	OR= 2.51 (1.76- 3.56)
			Knee injury	M, 100%: Injury previous 12 months	OR= 3.67 (1.79 – 7.49)†
			Calf injury	M, 100%; Incident injury at another localization	OR= 2.57 (1.42 – 4.67)†
	HQ	Wen et al., 1998 [17]	Overall injuries	History of previous injuries§	RR= 2.02 (1.268 – 3.21)†
			Shin injuries	History of old shin injuries§	RR= 7.24 (2.399 – 21.82)†
Orthotics	HQ	McKean et al., 2006 [47]	Running injury	Yes (< 40 years)	P= 0.001
				Yes (≥ 40 years)	P= 0.001
	HQ	Wen et al., 1997 [9]	Overall injuries	Shoe insert use	P=0.007
			Foot injuries	Shoe insert use	P=0.000

† Represents adjusted OR, HR or RR

§ RRs were calculated dividing the number of injured runners by the total number of runner-weeks accumulated (relative incidence ratios)

M, Men: CI, Confidence interval: ERLP, Exercise-related leg pain: OR, Odds ratio: HR, Hazard ratio: RR, Relative risk: MQ, Methodological quality: HQ, High quality

Table 7. Risk factors for running injuries with sex ratio

Independent variable	Author	Injury	Specification of independent variable	Sex Ratio*
Sex	Buist et al., 2010 [22]	Running-related injury (RRI)	M, 42.5%	0.7
	McKean et al., 2006 [47]	Running injury	M < 40 yrs.	0.8†
Age	Buist et al., 2010 [10]	Running-related injury (RRI)	M, 32.9%: Increase of age by 10 yrs	1.4
BMI	Buist et al., 2010 [10]	Running-related injury (RRI)	F, 67.1%	1.0
	Buist et al., 2010 [22]	Running-related injury (RRI)	M, 42.5%: 1 kg/m^2 increase	0.9
Navicular drop (ND)	Buist et al., 2010 [22]	Running-related injury (RRI)	F, 57.5%: ND (mm)	0.9
Previous sports activity	Buist et al., 2010 [10]	Running-related injury (RRI)	F, 67.1%: Previously active (non-axial load)	1.9
Running experience	Buist et al., 2010 [10]	Running-related injury (RRI)	M, 32.9%: Restarting running	0.7
			F, 67.1%: No previous running experience	1.1
	Macera et al., 1989 [45]	Lower-extremity injury	M, 83.2%: Running experience 0 – 2 yr.	0.7
	Macera et al., 1989 [45]	Lower-extremity injury	M, 83.2%: Marathon, during preceding 12 months	2
Surface	Macera et al., 1989 [45]	Lower-extremity injury	F, 16.8%: Concrete surface	4.2
Frequency	Macera et al., 1989 [45]	Lower-extremity injury	M, 83.2%: Run 6 or 7 days a week	0.8
Distance	Macera et al., 1989 [45]	Lower-extremity injury	M, 83.2%: Weekly distance for preceding 3 months; 32- 47.8 km	0.7
			M, 83.2%: Weekly distance for preceding 3 months; 48- 63.8 km	2.2
			M, 83.2%: Weekly distance for preceding 3 months 64.0+ km	0.4
Shoe use	Taunton et al., 2003 [24]	Overall injury	F, 75.6%: Running shoe age, 4 – 6 months	4.9†
History of previous injuries	Buist et al., 2010 [22]	Running-related injury (RRI)	M, 42.5%: > 3 to ≤ 12 months	0.5
			M, 42.5%: > 12 months	1.0
	Macera et al., 1989 [45]	Lower-extremity injury	M, 83.2%: Preceding 12 months	0.7

* Sex ratio > 1 represents higher risk for women and sex ratio < 1 represents higher risk for men

† Represents adjusted sex ratio

W, Women; M, men; BMI, Body mass index; ND, Navicular drop

Discussion

The purpose of this study was to synthesize current evidence on determinants of running-induced injuries of the leg in adults and to determine sex differences in risk profile for running injuries. We found strong and moderate evidence that previous leg injury and use of orthotics/ inserts increase the risk of leg injuries, respectively. Furthermore, there was only limited (one high-quality study) or no (one/two low-quality studies) evidence for other potential risk factors for running injuries (overall and injury specific).

Analysis of the sex ratios showed that women are at lower risk of running injuries than men. Factors that increased the risk of running-related injuries in women were older age, previous participation in non-axial sports (e.g. cycling, swimming, etc.), participating last year in a marathon, running on concrete, a longer weekly running distance (48–63.8 km) and wearing running shoes for 4 to 6 months. Men were at greater risk of such injuries if they restarted running, had a history of previous injuries, a running experience of 0–2 years, had a weekly running distance between 32–47.8 km, and having a weekly running distance more than 64 km per week.

Running injuries have a multifactorial origin that can be subdivided into personal, running/ training, and health and/or lifestyle factors [5,14,15]. These factors can reinforce each other and their influence may also be mediated by cultural or societal factors [49]. The importance of each factor, and hence its contribution to the risk of symptoms and injuries, varies among individuals and running environments. Personal factors investigated in this review focused on sex, age, anthropometric, and biomechanical factors; psychosocial factors were not investigated as risk factors for running injuries. Psychosocial factors seem to have a role inmusculoskeletal disorders [49–51] and thus future studies should investigate their role in running-related leg injuries.

Most running injuries are due to overuse [7], but only Wen et al. [9,17] and Bennett et al. [38] included or excluded overuse/acute injuries in their definition of injury, respectively. Overuse injuries of the musculoskeletal system generally occur when a structure is repeatedly exposed to loading forces. Forces lower than the threshold associated with acute injury ultimately lead to fatigue of that specific structure [52,53]. There is no standard definition of overuse running injury [8,54], but it should minimally include a musculoskeletal ailment that can be attributed to running and that causes a restriction of running speed, distance, duration, or frequency for at least a week [8]. Of the articles included in our review, that of Buist et al. [10,22] used definitions "any musculoskeletal pain of the lower limb or back causing a restriction in running for at least one day [10] or one week [22]" that matches the most with these criteria. The other studies did not define the period during which injury restricted running. Future research should use the definition of running injuries used by Buist et al. [10,22] or include a minimal time frame of running restriction when defining running-related injuries.

To our knowledge, this is the third review that systematically examined risk factors for running injuries. Five reviews of running injuries have been published in the past [4,5,14,15,19], and three of these narrative studies were published more than 20 years ago [5,14,15]. The most recent systematic reviews were published in 2007 [4] and 2014 [19]. Van Gent et al. [4] found strong evidence that a long training distance per week in men and previous injuries were risk factors for injuries; however, a long training distance per week was a protective factor for knee injuries. Although we also found previous injury to be a risk factor for running-related injuries, the variety in the other results can be explained by differences in the studies included. Seventeen articles, dating from 1982 to 2006, were included [4]: 10 studies were published after 2006 and were therefore not included in the study of Van Gent et al. [4]. As we used a minimal follow-up time of 1 month and an age of >18 years as inclusion criteria, the studies of Walter et al. [18] and Satterthwaite et al. [16] were not included in our review. The finding of Van Gent et al. [4] that longer training distance per week is a protective against knee injuries could not be confirmed because studies providing evidence for this association were not included in our review.

The recent published review by Saragiotto et al. [19] included only prospective studies which mentioned running or runners in the abstract/title. Moreover, articles that studied risk factors for specific injuries (e.g. medial tibial stress syndrome) were excluded in their systematic review. Furthermore, Saragiotto et al. [19] included all categories of runners, this in contrast with our study population consisting of novice runners, long-distance runners, both recreational and/or competitive. In their study [19] also pooling of data was not possible due to the large heterogeneity of the statistical methods used across studies. However, although they did not perform a best evidence synthesis and used different inclusion and exclusion criteria, the conclusion that previous injury is a risk factor for running injuries was the same as in our study.

Risk Factors for Running Injury

We decided to classify the different risk factors for running injuries according to the existing literature of systematic reviews (personal, running/training, health and lifestyle) [4,14,15], to facilitate comparison between the reviews. However, applying a public health approach to sports injury prevention as described by Finch [55], conceptualizing risk factors as modifiable and nonmodifiable provides additional insight [56]. Modifiable risk factors associated with running injuries provide the base for developing running injury prevention interventions, whereas nonmodifiable risk factors are important for risk stratification and targeted prevention [56].

Nonmodifiable Risk Factors for Running Injuries

History of injury. Previous injury was consistently associated with running injuries and especially in men. The lack of association between previous injury and running injuries in women might be because most of the included studies investigated female novice runners with minimal running experience and few injuries in the past [10,22,24,39–41,43]. It is not clear whether a high rate of re-injury is due to incomplete healing of the original injury, an uncorrected biomechanical problem, or recall bias

and/or the definition of the injury. Previous lower extremity injuries that have healed completely (i.e., the return of full, pre-injury joint range of motion, musculoskeletal strength, and proprioception) should not increase the risk of a subsequent lower extremity injury [57]. However, injuries that give rise to permanent structural or biomechanical malfunction and/or dysfunctional coordination increase the risk of future running injuries [58]. In our review, three high-quality studies [22,42,45] found a history of previous leg injury to be a risk factor in men. However, the definition of "previous injury" differed in the various studies, in terms of its nature (e.g. acute or gradual onset), whether it is running related or not, when it occurred and how long it lasted. It is essential to know the extent and characteristics of recovery from a previous injury [57]. Lastly, in most studies participants were asked about injuries in the previous year, which means that recall bias could be a problem.
In conclusion, previous (running) leg injury seems an important risk factor for running injuries. Further research should focus on a clear definition of "previous (running) injury" and should more focus on recovery processes to judge the possibility of re-injury including the time of occurrence, and on minimizing recall bias by reducing the time frame of recall.

Modifiable Risk Factors for Running Injuries

Training. Overuse running injuries are suggested to be the result of training errors [8] and our results confirm this. On the basis of this review, it seems that the ideal training intensity has not yet been established. Runners with a high training frequency and/or running distance appeared to be more susceptible to overuse injuries, especially those runners who have no running experience and, seemingly contradictory, runners who are experienced and who have run, perhaps long distances, for a longer time. Van Gent et al. [4] found strong evidence that men with a higher weekly training frequency were more prone to running injuries. However, running only once a week could lead to overuse injuries, especially in women [24]. This is probably because running stresses the musculoskeletal system [8], which does not have time to adapt to this type of exercise because of the low frequency of running.
In conclusion, overuse running injuries should be prevented by optimizing and personalizing training, bearing in mind the (limited) evidence that running/training-related factors influence the risk of injury.

Orthotic/insert. Foot orthoses are widely used to treat existing pathological conditions and to prevent overuse injuries [59]. They function in two ways: 1) the insert acts as a cushion that absorbs shock transmitted to the lower limb, and 2) they compensate for biomechanical deficiencies of the foot, such as excessive pronation and differences in leg length [60]. Most findings of this review contradict these statements. McKean et al. [47] and Wen et al. [9] showed that runners with orthotic/inserts were at higher risk of running injuries, although it is possible that runners who are more prone to injury are given orthotic/inserts earlier. However, given the findings about the role of the navicular drop [22], alignment [9,17], and force distribution [40,41] in running-related injuries, it is doubtful that compensating biomechanical deficiencies with an orthotic/insert is effective in preventing running injuries. In conclusion, orthotics/inserts do not seem useful to compensate for biomechanical deficiencies.

Sex Differences

Differences between the health of men and women are a major concern to European health authorities [20]. Only five high-quality studies [10,22,24,45,47] investigated the effect of runner's sex on the risk of running injuries. However, given the small number of studies that investigated this, it was not possible to establish sex-specific profiles for risk factors.
Two high-quality studies investigated the relation between previous injury and running injuries and presented data for men and women separately, so that it was possible to calculate a sex ratio. When the criteria of Van Tulder [33] were used to determine the level of evidence for sex differences, two studies [22,47] provided moderate evidence that men (< 40 year) had a higher risk of running-related injuries and two studies [22,45] provided moderate evidence that men had a higher risk of running-related injuries when having a previous injury; the other studies did not provide evidence of sex-related differences in risk of running injuries. However, physical therapists, sports physicians, etc. can provide sex-specific advice for the prevention of running injuries, and trainers and coaches can tailor their training advice to individual runners. More prospective longitudinal studies are necessary and should analyze data for men and women separately, in order to obtain evidence-based, sex-specific risk profiles [20,61].

Risk of Bias & Study Limitations

As risk factors were operationalized as dichotomous, ordinal, or even continuous variables, it was not possible to calculate a meaningful pooled summary of outcomes. Moreover, conclusions made after data pooling might have been of limited value given the heterogeneity in definition of running injury in the various studies.
Quality scoring systems are used in an attempt to address possible methodological shortcomings that could threaten the validity of study results [30]. We created our quality scale based on the lists used by the Cochrane Collaboration to assess cohort studies [27] and on lists used in previous studies [28–30]. One of these lists [29] was quantified by West et al. [62] in a study that evaluated quality-rating systems for observational studies. The scoring list of Ariëns et al. [29] scored positive on six and partially positive on one out of nine domains for assessing study quality [62]. While the usefulness of quality control is disputed [62] as it is difficult to determine how to weight each item in an overall quality score, sum scores are considered helpful in a systematic review for distinguishing between studies with a low or a high risk of bias [62,63]. We evaluated the quality of the included studies in order to gain insight into the risk of bias and therefore to enable us to draw meaningful conclusions. A point of concern is that many of the included studies did not clearly describe the participation rate of the target group, which limits the generalizability of findings [64].
This study had some limitations. All included studies, prospective and retrospective,

were assessed using the same quality list. Because it would be better to adjust the list for a retrospective design, a second quality analysis was done for the two retrospective studies reviewed [9,47], such that item 2 ("participation rate is at least 80% from the identified target group") and 3 ("the participation rate at main moment of follow-up is at least 80% or the nonresponse is not selective") were scored as "not applicable" in the scoring list. This did not influence the quality score of these articles (both remained high quality), and therefore had no influence on the results of our best evidence syntheses.
By our inclusion criteria (e.g. long-distance runners recreational and/or competitive) for selecting the original studies, a broad spectrum in the type of runners (novice, track and field, etc.) was selected. When the inclusion criteria were more strictly defined, our results could be presented stratified for each group of runners. However, the number of studies per type of runners would be too small to give useful information and by choosing a broader spectrum of type of runners, our results are more generalizable to the total adult running population.
Although we performed an extensive literature search, it is likely that both selection and publication bias influenced the results. Future research, in which running injury is uniformly defined, may indicate whether the factors found in our review are true risk factors.

Conclusion and Implications

More high-quality studies of risk factors for running injuries are needed before strong conclusions can be drawn about the relevance of specific risk factors. Furthermore, consensus must be achieved about the definition of running injuries, and large cohort studies are needed to investigate different types (biomechanical, hormonal, psychological, etc.) of risk factors with emphasis on potential differences between men and women. To minimize bias, future studies should pay attention to recall of previous running injuries, follow-up time, and the participation rate.
This review found strong evidence that previous leg injury is a risk factor for running-related leg injuries. Some sex-specific risk factors were identified, but not enough studies investigated differences between men and women to obtain more definite results. Running injuries seem to have a multifactorial origin, but on the basis of our findings, efforts to prevent injury should focus on runners, especially men, with a history of running injuries and provide customized training and/or specific exercises. The use of orthotics/inserts should be discouraged.

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Chapter 4

REPRODUCIBILITY OF AND SEX DIFFERENCES IN COMMON ORTHOPAEDIC ANKLE AND FOOT TESTS IN RUNNERS

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Abstract

Background: For future etiologic cohort studies in runners it is important to identify whether (hyper)pronation of the foot, decreased ankle joint dorsiflexion (AJD) and the degree of the extension of the first Metatarsophalangeal joint (MTP1) are risk factors for running injuries and to determine possible sex differences. These parameters are frequently determined with the navicular drop test (NDT) Stance and Single Limb-Stance, the Ankle Joint Dorsiflexion-test, and the extension MTP1-test in a healthy population. The aim of this clinimetric study was to determine the reproducibility of these three orthopaedic tests in runners, using minimal equipment in order to make them applicable in large cohort studies. Furthermore, we aimed to determine possible sex differences of these tests.

Methods: The three orthopaedic tests were administered by two sports physiotherapists in a group of 42 (22 male and 20 female) recreational runners. The intra-class correlation (ICC) for interrater and intrarater reliability and the standard error of measurement (SEM) were calculated. Bland and Altman plots were used to determine the 95% limits of agreements (LOAs). Furthermore, the difference between female and male runners was determined.

Results: The ICC's of the NDT were in the range of 0.37 to 0.45, with a SEM in the range of 2.5 to 5 mm. The AJD-test had an ICC of 0.88 and 0.86 (SEM 2.4° and 8.7°), with a 95% LOA of –6.0° to 6.3° and –5.3° to 7.9°, and the MTP1-test had an ICC of 0.42 and 0.62 (SEM 34.4° and 9.9°), with a 95% LOA of –30.9° to 20.7° and –20° to 17.8° for the interrater and intrarater reproducibility, respectively.
Females had a significantly ($p < 0.05$) lower navicular drop score and higher range of motion in extension of the MTP1, but no sex differences were found for ankle dorsiflexion ($p \geq 0.05$)

Conclusion: The reproducibility for the AJD test in runners is good, whereas that of the NDT and extension MTP1 was moderate or low. We found a difference in NDT and MTP1 mobility between female and male runners, however this needs to be established in a larger study with more reliable test procedures.

Background

Running has become popular in the last decades [1]. The Royal Dutch Athletics Federation (KNAU) has estimated that about 12.5% of the Dutch population runs regularly, and that the popularity of running events is still growing [2]. Running is an inexpensive form of vigorous-intensive physical activity and can be done anywhere and at anytime. It is also a basic aspect of many recreational and professional sports. However, running can cause injuries, especially of the lower extremities, with incidences varying between 20% and 79% and with the knee as most common site of injury followed by lower leg and foot [3]. Knowledge of potential risk factors is needed in order to preventrunning injuries [4]. The exact causes of running injuries remain to be determined, but are likely to be diverse [3].

For future etiologic cohort studies of runners it is important to identify whether (hyper)pronation of the foot, decreased ankle joint dorsiflexion (AJD) and the degree of the extension of the MTP1 are risk factors for running injuries. To measure the extent of foot pronation, AJD and the extension of the MTP1, reproducible orthopedic tests are essential.

Bennett et al. [5] and Buist et al. [6] found in their prospective studies a positive navicular drop test (NDT > 10 mm) as predictor for running related injuries. Inthe same study of Buist et al. [6] and in the case–controlstudy of Van Mechelen [7] dorsiflexion was not found as risk factor and no difference was found in ankle joint mobility between injured and non-injured runners. Further prospective studies are needed to include/exclude the ankle range of motion as possible risk factor for running injuries. Also the extension of the MTP1 is, by our knowledge, not included in etiology studies as a risk factor for running injuries and needs future research.

To determine the extent of ND, AJD and extension of the MTP1, the navicular drop test (NDT), a method to classify the degree of foot pronation, the weight bearing AJD-test and the MTP1-test are used. The NDT is moderately reliable [8,9]. In the study of Vinicombe et al. [8], five clinicians performed the NDT twice in 20 healthy participants (13 women and 7 men, mean age 20 ± 2 years), with an ICC ranging from 0.33 to 0.76, with a 95% confidence interval of 1.5 mm to 3.5 mm. Shultz et al. [9], in a study of the reliability of measurements of lower extremity anatomical characteristics, reported the intrarater and interrater reliability of the NDT to be 0.91–0.97 and 0.56- 0.76, respectively.

Measurement of ankle joint dorsiflexion (AJD) with an inclinometer and extension of the MTP1 in a weightbearing position with a goniometer proved to be reliable orthopaedic tests [10,11]. Munteanu et al. [11] found measurements of the AJD, with an inclinometer and in a weight- bearing position with the knee extended, to have a high intra- and interrater reliability (>0.77 and > 0.90, respectively) in 30 asymptomatic participants. Hopson et al. [10] found an ICC of 0.98 for the reliability of the MPT1 extension test in static weight-bearing position when measured in 10 women and 10 men aged 21– 43 years.

However, there are no data in the literature on the reliability of these orthopaedic tests in healthy adult runners, a population of particular interest for screening purposes. Clinical measurements of the ND, AJD and extension of the MTP1 can be used to guide decisions regarding preventive treatment strategies in runners, including the use of orthotics and modification of footwear.

In conclusion, above mentioned studies focused on reliability of the NDT, AJD-test and extension MTP1-test in healthy adults. However, these tests seem to be important to identify runners with higher injury risk and for prevention purpose. Moreover, in this study, the protocols in the literature of the NDT [8], AJD-test [11] and extension MTP1-test [10] were adapted for the use in our planned prospective cohort study of female runners (n = 433). This adaptation was necessary for practical reasons, which required that these orthopaedic tests are performed in maximal 10 minutes, on location and with a minimum of measurement tools and equipment. For the NDT [8], in our protocol a ruler was used instead of a blank card [12] and the sitting position was used as neutral position of the foot instead of palpating the talar head [13], so the NDT could be determined directly and the measurement time was minimized. The performing times of the protocols of the AJD-test [11] and the extension of MTP1-test [10] were optimized by refraining from using a tapeline and standardized step length, but extra attention was paid to maximal stretch of the posterior leg and MTP joint, respectively. Consequently, by deviating of existing protocols, the agreement (as a characteristic of the protocol and measurement instrument itself) of these three tests had to be determined as well.

Furthermore, we hypothesized that there is a difference between sexes based on several runner studies [6,14-17] which showed differences in risk profile between male and female runners. This sex difference, regarding the musculoskeletal system, can partly be explained by the difference in NDT, AJD- and MTP1 mobility. In a cohort study of Buist et al. [6] of novice runners, sex-specific risk factors were found: women who had higher values of the NDT were more prone to running related injuries (Hazard ratio 0.85; 95% confidence interval 0.75- 0.97). Although not yet identified as a risk factor, differences in the AJD and the extension of the MTP1 between males and females could also (partially) explain the risk profile difference between males and females. A limited function will change muscle activity and joint loading in the functional chain. Hence, the aim of this study was to develop and assess the intrarater and interrater reliability and agreement of the NDT, AJD test and extension MTP1 test in weight-bearing position in healthy runners. Secondly, we wanted to compare outcomes of these tests between female and male runners.

Methods

Ethics statement The study was approved by the Medical Ethical Committee of the Radboud University Nijmegen Medical Centre. Written informed consent of the participants was obtained before the study. The participants of the images and videos provided a written consent for the publication of their images and videos.

Participants A group of 46 recreational runners (running minimally once a week and minimally 5 km), who were members of a track and field club, running groups, or running on individual basis, was recruited by physiotherapists, trainers, and coaches of the local track and field clubs in Utrecht, the Netherlands. Potential participants were personally invited to participate, were informed about the study and were given the opportunity to volunteer. Runners were eligible if they were 18 years or older, were healthy, and running injury-free at that moment. None of the participants complained of lower extremity pain or spinal pain, and none had medical or neuromusculoskeletal disorders that limited participation in work, sports, or exercise. Forty two runners met the inclusion criteria. All participants provided written informed consent and analyses were performed on anonymous data. The characteristics of the runners who participated in our study are showed in Table 1.

Table 1 Demographics of the runners participating in the study

	Total (n = 42)	Males (n = 22)	Females (n = 20)
	Mean ± SD	Mean ± SD	Mean ± SD
Age (yrs)	38.2 ± 12.4	39.1 ± 14.7	37.2 ± 9.3
Weight (kg)	71.3 ± 12.4	80.1 ± 8.3	61.6 ± 8.0
Height (cm)	175.4 ± 8.8	181.8 ± 6.3	168.4 ± 4.9
BMI (kg/m^2)	23.1 ± 3.0	24.3 ± 2.9	21.7 ± 2.5
Years of running (yrs)	9.8 ± 11.1	10.5 ± 12.6	8.9 ± 9.5
Weekly training frequency (days)	2.4 ± 1.5	2.6 ± 1.9	2.1 ± 0.7
Weekly training distance (km)	22.1 ± 22.2	27.1 ± 28.8	16.6 ± 9.4

SD = Standard Deviation, BMI = Body Mass Index.

Procedures

The three tests were conducted by two sports physiotherapists (HD and MW) who were specialized in running injuries, board-certified clinical specialists in sports physiotherapy, and members of the International Federation of Sports Physical Therapy (IFSPT). Both examiners attended three 1-hour training sessions prior to data collection, to increase consistency in testing procedure and interpretation.

After giving written informed consent, each runner completed a baseline questionnaire about his/her running status and injury history. The height and weight were determined. The runners were randomly assigned to the two examiners (MW and HD). To determine intrarater reliability, runners were measured twice by examiner HD (HD_1 and HD_2). Figure 1 shows a flow chart of the procedure. Both examiners completed all three static tests once for both legs and feet, randomized in test order by computer, with minimally 10 minutes between measurements of examiner HD. All measurements of one runner were taken on the same day.

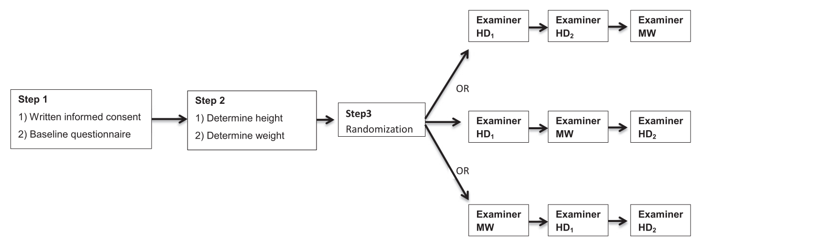

Figure 1 Flowchart of the procedure of measurements of examiner Maarten van der Worp (MW) and examiner Holger Drechsler (HD); twice; HD_1 and HD_2.

Navicular Drop Test (NDT)

In the current study, a modified version of the navicular drop test described by Vinicombe et al. [8] was used. In our protocol a ruler was used instead of a blank card [12] and the sitting position was used as neutral position of the foot instead of palpating the talar head [13].

The runner was sitting upright with arms crossed in front of the chest, feet flat on the ground and equal weight on both sides, with hip and knees flexed at 90°, and the most medial aspect of the navicular bone was marked. The un-weighted navicular position was the distance from the floor to the point marked on the navicular bone, measured with a ruler. The runner was then asked to stand, without moving the feet, equal weight bearing on both legs and the distance between the navicular marker and the floor was measured again (Figure 2). Then the runner was asked to stand on one leg by flexing the contra-lateral hip and knee 90°, holding a chair for balance and maximum weight bearing on the supporting leg was encouraged.

Figure 2 Measuring the height of the medial aspect of the navicular bone in stand position, with a ruler.

The Single Limb-Stance position was selected because this position reflects the position of the foot during the mid-stance phase of gait [18] and a ruler was used so the navicular drop could directly be determined. The difference between the distance from the navicular marker to the floor in resting position versus standing (NDT; Stance) and resting position versus single limb-stance (NDT; Single Limb-Stance) was scored as the navicular drop standing and navicular drop single limb-stance, respectively [8,19].

Ankle joint dorsiflexion test

For measuring the ankle joint dorsiflexion, the protocol described in the study of Munteanu et al. [11] was used, only without using a tapeline. The runner was asked to step forward with the left leg, so that the right knee was fully extended. The right foot was straight, in line with the left foot. The runner leaned forward until maximum stretch was felt in the right leg while keeping the right knee fully extended and the right heel in contact with the ground; thismovement was repeated. If necessary, the runner could put his or her hands on the wall in front, just for keeping balance. The left leg was in a comfortable position to maintain balance and to allow dorsiflexion of the right ankle. The angle between the right tibia and the vertical axis was then measured using a calibrated digital inclinometer (Pro 360 digital protractor; Smart Tool Technology, Inc, Oklahoma City, OK; accuracy = ± 0.1°, maximum resolution = 0.1°). The inclinometer was positioned on a mark made on the mid-part of the anterior side of the tibia between the upper edge of tibial tuberosity and the anterior joint line of the ankle (Figure 3) [11].

Figure 3 Measurement with an inclinometer of ankle dorsiflexion with extension in the knee.

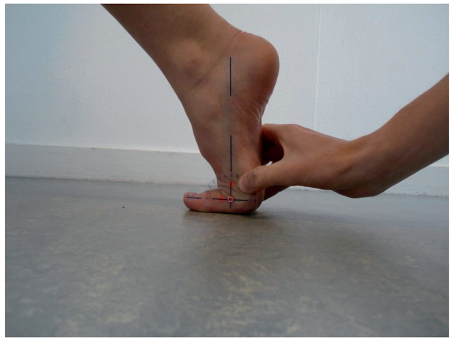

Figure 4 Measurement with a goniometer of the maximal extension of the first metatarsophalangeal joint.

Extension First Metatarsophalangeal Joint test (MTP1-test)

For measuring the mobility of the MTP1 the protocol, as used in the study of Hopson et al. [10]], was slightly modified (not standardizing the step length) and used in this study. With the runner lying on a treatment table, the MTP1 was identified by passive dorsiflexion and plantar flexion of the hallux. Marks were made on the medial aspect of the joint centre and, after palpation, on the medial side of the shaft of the first metatarsal and the proximal phalanx of the hallux. Then the runner was asked to step forwards and to raise the heel of the foot behind, with full extended knee and extending the MTP1 as far as possible while maintaining step length and hallux contact with the floor; the runner could use the wall for balance, if necessary. Because the knee was fully extended, the maximum elongation of MTP1 reached by instruction and holding balance was no problem, the size of the step length did not affect the outcome of the MTP1 mobility.

A goniometer (MSD pocket goniometer, baseline 180 degree, transparent plastic) was placed on the skin markers with the centre of the goniometer at the metatarsophalangeal joint, one goniometer-arm line crossing the centre of the mark on the shaft of the first metatarsal and the other goniometer-arm line crossing the centre of the mark of the proximal phalanx of the hallux, respectively (Figure 4). The value recorded was the maximum MTP1 extension angle while the runner maintained his or her step length position.

Statistical analysis

The data from the right and left leg and feet were used separately in all calculations. Intraclass correlation coefficients (ICCs) were calculated. ICC model 2.1, with absolute agreement and single measures, was used for intrarater reliability and ICC model 2.2 with absolute agreement and single measures for interrater reliability, respectively [20,21]. The guidelines used for the interpretation of the ICCs were as follows: 0.0 to 0.25 indicated little if any correlation; 0.26 to 0.49 indicated low correlation; 0.50 to 0.69 indicated moderate correlation; 0.70 to 0.89 indicated high correlation; and 0.90 to 1.00 indicated very high correlation [22].

To determine the agreement between the three orthopaedic tests, the standard error of measurement (SEM) and the 95% limits of agreement (LOA) were calculated as measure of 'total error' (systematic and random error combined) [23]. SEM "agreement" was calculated for taking in account possible systematic errors [24]. Bland and Altman plots were created by plotting the difference between each measurement and the mean difference of the measurement for the intrarater and interrater agreement, to visualize the possible systematic error and random error of the measurements of one examiner (HD) or the difference between the examiners (HD and MW) [25].

For sex differences comparisons, means, standard deviations, mean differences and 95% confidence interval (CI) of the dependent variables of the three tests were calculated, for which the data of the measurement of examiner MW were used. Independent t-test with an alpha value of 0.05 was used to evaluate sex differences comparisons. Data analysis was performed using SPSSVersion 22.0 (SPSS Inc, Chicago, IL).

Results

Table 2 presents the mean and standard deviation of the measurements of the two examiners (HD twice; HD1 and HD2), the ICCs with 95% confidence intervals and the SEMs with 95% LOA's.

Navicular Drop Test (NDT)

NDT Stance: Interrater and intrarater ICCs of the NDT Stance measurements were low (ICCs; 0.45 and 0.43, respectively) and with a SEM of 3.2 mm and 2.5 mm respectively. The Bland & Altman plots with the 95% LOAs, Figure 5A and B, for interrater and intrarater reliability respectively, illustrate the low agreement.

Table 2 Measurement outcomes of the two examiners MW and HD (twice) and the reproducibility the three orthopaedic tests in all participants (n = 42)

	HD_1 Mean ± SD	MW Mean ± SD	HD_2 Mean ± SD	Reliability test	ICC (95% CI)	S.E.M (95% LOA)
NDT Stance (mm)	6.2 ± 2.7	5.8 ± 2.8	6.0 ± 2.8	Interrater	0.45 (0.26- 0.60)	3.2 (−6.1- 5.3)
				Intrarater	0.43 (0.23- 0.59)	2.5 (−5.6- 6.1)
NDT SL-S (mm)	5.8 ± 3.1	5.1 ± 2.8	5.8 ± 3.1	Interrater	0.41 (0.21- 0.57)	5.0 (−7.2- 5.8)
				Intrarater	0.37 (0.18- 0.54)	2.5 (−7.0- 6.9)
AJD test (°)	48.1 ± 6.6	48.2 ± 6.1	46.8 ± 6.0	Interrater	0.88 (0.82- 0.92)	2.4 (−6.0- 6.3)
				Intrarater	0.86 (0.80- 0.91)	8.7 (−5.3- 7.9)
MTP I test (°)	79.4 ± 10.9	74.2 ± 13.1	80.5 ± 10.8	Interrater	0.42 (0.23- 0.59)	34.4 (−30.9- 20.7)
				Intrarater	0.62 (0.47- 0.74)	9.9 (−20.0- 17.8)

HD_1 = first measurement examiner HD, MW = measurements examiner MW, HD_2 = second measurements examiner HD, SD = Standard Deviation, NDT = Navicular Drop Test, NDT Stance = Navicular Drop Test Stance, NDT SL-S = Navicular Drop Test Single Limb-Stance, AJD = Ankle Joint Dorsiflexion, MTP I = First Metatarsophalangeal Joint, ICC = Interclass Correlation Coefficients, CI = Confidence Interval, S.E.M. = Standard Error of Measurement, LOA = Limits Of Agreement.

NDT Single Limb-stance: The ICC of the interrater and intrarater reliability of the NDT Single Limb-Stance was low. The SEMs were 5 mm and 2.5 mm for the interrater en intrarater agreement, respectively. Figure 6A and B shows the Bland & Altman plots with the 95% LOAs of –7.2 to 5.8 mm and –7.0 to 6.9 mm for the interrater and intrarater agreement, respectively.

Table 3 Sex differences of the three orthopaedic tests, with the mean, standard deviation (SD), mean difference, 95% confidence interval and p-values of the measurements outcomes of examiner MW

	Male (n = 22) Mean ± SD	Female (n = 20) Mean ± SD	Mean difference	95% CI	P-Value
NDT Stance (mm)	6.7 ± 3.1	4.9 ± 2.1	1.8	0.6- 2.9	0.003†
NDT SL-S (mm)	6.0 ± 3.0	4.1 ± 2.2	1.9	0.7- 3.1	0.002†
AJD-test (°)	47.7 ± 5.6	48.9 ± 6.6	1.2	−3.9- 1.4	0.364
MTPI-test (°)	69.9 ± 11.2	79.0 ± 13.5	9.1	3.8- 14.5	0.001†

SD = Standard Deviation, NDT = Navicular Drop Test, NDT Stance = Navicular Drop Test Stance, NDT SL-S = Navicular Drop Test Single Limb-Stance, AJD = Ankle Joint Dorsiflexion, MTP I = First Metatarsophalangeal Joint, CI = Confidence Interval, † = significant difference between males and females ($p < 0.05$).

Ankle Joint Dorsiflexion Test (AJD-Test)

The interrater and intrarater reliability of AJD measurements was high for both (ICCs = 0.88 and 0.86, respectively). The agreement between examiners was lower than within examiners (SEM 2.4° and 8.7°, respectively). The Bland and Altman plots, see Figure 7A and B, reflect the high degree of agreement with 95% LOA's of –6.0° to 6.3° and –5.3 to 7.9° for the interrater and intrarater agreement, respectively.

Extension First Metatarsophalangeal Joint Test (MTP1-Test)

The interrater reliability of the MTP1 test was low (ICC 0.42 and SEM 34.4°) whereas the intrarater reliability was moderate (ICC 0.62; SEM 9.9°). Figure 8A and B, the Bland & Altman plots with the 95% LOAs, illustrates the low and moderate agreement for interrater and intrarater agreement, respectively

Sex differences

The outcome measurements of the three orthopaedic tests were described in Table 3. Females demonstrated a significantly lower navicular drop (both for Stance and Single Limb for Stance) with a mean difference of 1.8 mm ($p = 0.003$) and 1.9 mm ($p = 0.002$), respectively and a higher extension of MTP1, with a mean difference of 9.1° ($p = 0.001$). No difference was found in the mobility of the AJD, p-value ≥ 0.05. See Table 3.

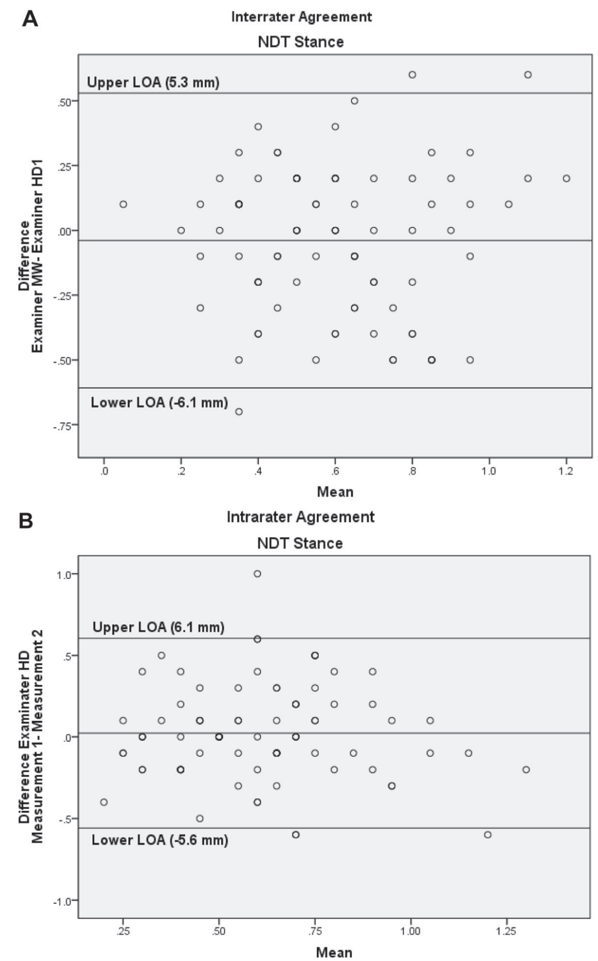

Figure 5 Bland-Altman plots for the interrater (A) and intrarater (B) agreement of the Navicular Drop Test (NDT) Stance, with the 95% limits of agreement (LOA).

Discussion

This study showed a good reproducibility of the AJDtest, with an ICC of > 0.85 for the reliability and a small range of 95% LOAs, indicating a good agreement. However, the reproducibility of the NDT and extension MTP1-test was moderate to low. Furthermore, a difference was found between females and males for the NDT (Stance and Single Limb-Stance) and the extension of the MTP1, but not for the mobility of the AJD.

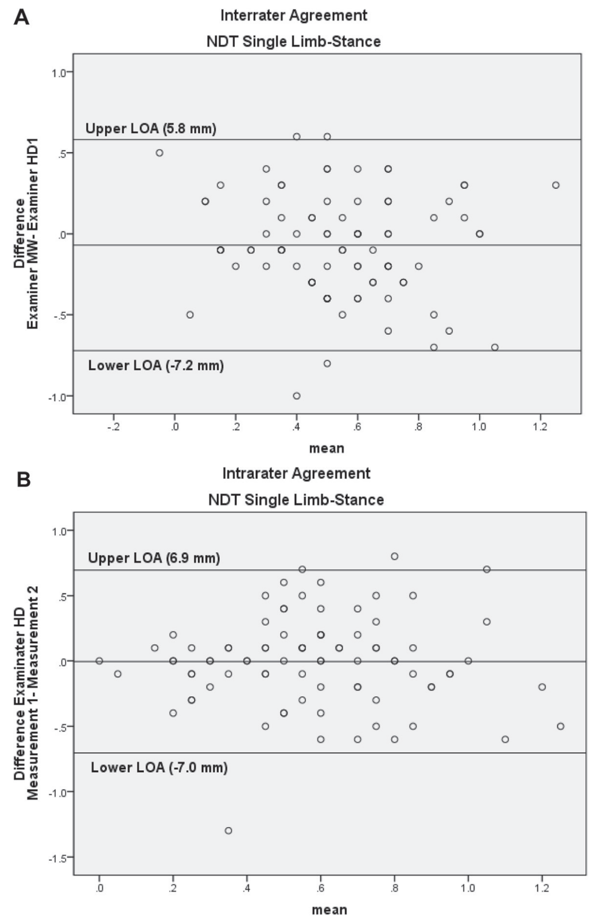

Figure 6 **Bland-Altman plots for the interrater (A) and intrarater (B) agreement of the Navicular Drop Test (NDT) Single Limb-Stance, with the 95% limits of agreement (LOA).**

Navicular Drop Test (NDT)

Studies have reported NDT Stance values for the intrarater reliability in the range of 0.51 to 0.97 [9,26-28] and interrater reliability of 0.46- 0.95 [9,12,27,28]. While our NDT Stance values were similar, with a smaller SD, the intrarater reliability was lower and the interrater reliability in the same range. The SEM of 2.5 mm for the intrarater agreement in our study is in the range of 0.4- 2.7 mm as reported in the literature [9,12,26,27]. However, the 95% LOA was higher, 11.7 mm, as compared to the study by Evans et al. [12], who found a 95% LOA of 5.2 mm. Our SEM for the interrater agreement (3.2 mm) was higher as reported in the literature with a SEM in the range of 1.4- 2.7 mm [9,27,28]. Also the 95% LOA's for the interrater agreement were wider than those in the study of Shultz et al. [9] who found values between 1.4 and 2.6 of the 95% LOAs by four testers. In addition, both ICC's of 0.41 and 0.37 and SEMs of 5 and 2.5 mm for the interrater and intrarater reproducibility of our findings for NDT Single Limb-Stance differ from those of Vinicombe et al. [8], who reported a

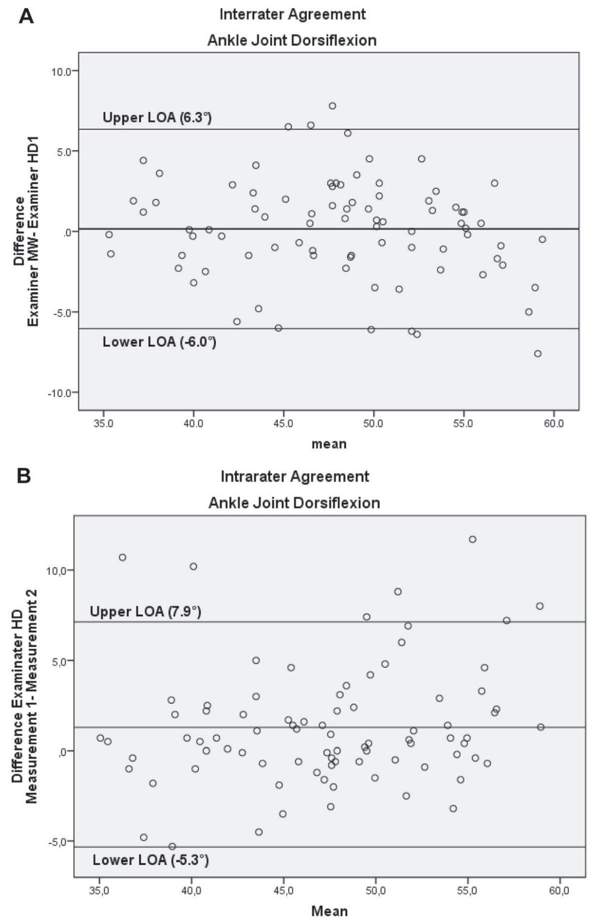

Figure 7 **Bland-Altman plots for the interrater (A) and intrarater (B) agreement of the ankle joint dorsiflexion, with the 95% limits of agreement (LOA).**

higher reliability (range of 0.33 to 0.76) and lower SEMs of 1.06 to 1.87 mm. So, our results were disappointing. The most important factors that influence reliability and agreement are the experience of the examiners [9,12], the consistency of placing the subtalar joint in its neutral position by palpation of the talar head [29-32], and identification of the navicular bony landmark [13]. As we used the strategy (sit-to-stand) of McPoil et al [13] to ensure a difference in the neutral and resting positions of the talar, we considered it unnecessary to place the subtalar joint in neutral position, by palpating the talar head. However, it is possible that small differences in neutral foot position could explain the lower reproducibility of our measurements compared with those of the literature [8,9,12,27,28]. Sell et al. reported that the subtalar neutral position can be measured reliably by palpating the talar head. This should be included in our protocol, to guarantee uniformity of neutral position of the foot. Two experienced examiners, who were extensively trained in standardization of the tests, performed the measurements. While the examiners had no difficulty in

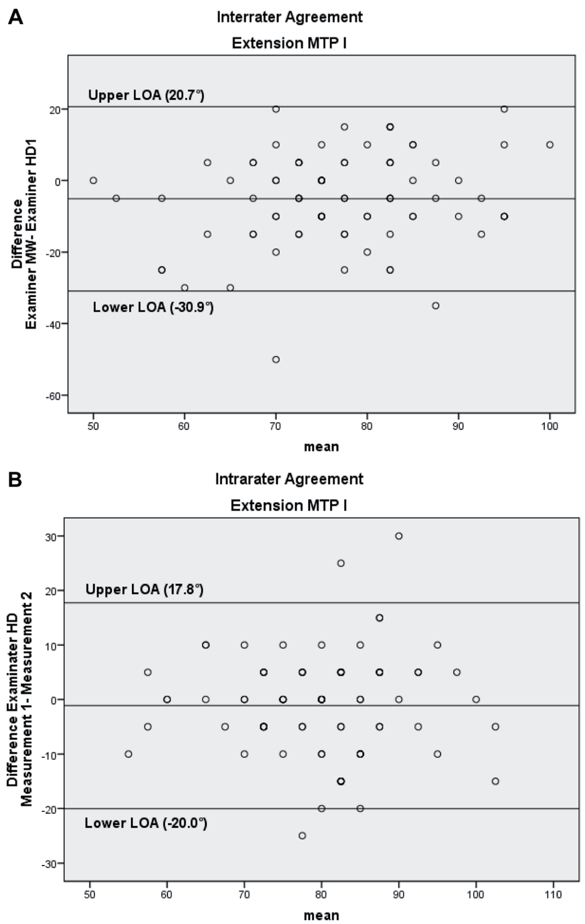

Figure 8 Bland-Altman plots for the interrater (A) and intrarater (B) agreement of the extension of the first metatarsophalangeal joint (MTP1), with the 95% limits of agreement (LOA).

identifying the navicular bony landmark, they had difficulty locating the navicular tuberosity because of anatomical variation among individuals. In some cases, the medial prominence of the navicular was easily palpated and marked. In other cases, the morphology of this bone made the location of the reference point difficult.

The navicular bony landmark was marked on the skin with the runner in sitting position but moving the skin could move the marker. Sell et al. [27] reported ICC values of 0.73– 0.96, with the landmark being identified with subjects in prone position, which may be the most optimal way to identify the navicular bony landmark.

Another explanation for the lower reliability in our study is that we measured the height of the navicular bony landmark with a ruler. The ruler was used so to observed the navicular drop directly and it is less time consuming than using a blank card [8], metrecom [26] or digital images [13]. However, as the ruler is placed at an angle, measurements might differ depending on the angle at which the examiner looks at the ruler. A 1.5 × 3-inch note card, as used by Sell et al. [27], might be better than a ruler. Using digital height gauge in measuring the navicular height for avoiding reading error could be most ideal. Taken together, we conclude that we need to adapt the measurement protocol to increase reproducibility.

Ankle joint dorsiflexion

We followed the advice of Gatt and Chockalingam [33] to standardize the AJD test for runners. With the running position as basis, four variables were standardized: subject position, foot position, placement of the ankle joint axis, and force on the plantar forefoot. We found that AJD can be reliably measured in a weight-bearing position with the knee extended by experienced examiners using a digital inclinometer in runners. Although the data were for asymptomatic runners, they were comparable to the findings of Munteanu et al. [11]. Munteanu found for the intrarater reliability an ICC of 0.77 with a 95% LOA of −9.1° to 8.3° and an interrater reliability of 0.95 (ICC) and a 95% LOA of −5.7° to 8.3°. Interrater and intrarater reliability was the same in our study, possibly reflecting the experience of the examiners, the efficacy of pre-training, the standardized protocol, and the subjects (healthy runners). We did find a systematic error of 1.3° ($p < 0.05$) for the intrarater reliability of the AJD test and a SEM "agreement" of 8.7°. When calculating the SEM "consistency" and not taking account the systematic errors [24], we obtained a value of 2.34°. We could not identify the source of this systematic error.

In order to interpret the agreement between and within the examiners, 95% LOAs were calculated [21], to determine to what extend whether a difference in AJD can be attributed to a measurement error. The observed difference should be greater than 6.3° and 7.9° when measurements were performed by the same examiner or different examiners, respectively.

Extension First Metatarsophalangeal Joint (MTP1)

MTP1 extension was measured in a static weight-bearing position, to simulate the running toe-off. To our knowledge, the reproducibility of this test has not been tested in runners previously. Hopson et al. [10] found, in a cohort of 20 healthy adults subjects, much higher reliability values. In our study, we marked the bony landmarks each time MTP1 extension was measured, whereas Hopson et al. [10] marked the bony landmark once for all measurements which could explain the difference in reliability. Furthermore, Hopson et al. [10] drew lines on the first metatarsal, the estimated joint centre, and on the hallux as reference lines for measurements, whereas we used dots to perform the marking quicker. This may decrease the precision with which the goniometer was placed. Step length was also standardized in the study of Hopson et al. [10]. In our protocol the knee was fully extended and the maximum stress on the MTP1 joint reached without balance problems. The possible difference in the size of the step length was not expected to influence the outcome of the MTP1 mobility.

MTP1 extension values of our study (79.4 ± 10.9°, 74.2 ± 13.1° and 80.5 ± 10.8°) were similar to that reported by Buell et al. [34], namely, 82° on passive extension of MTP1 with measurements being validated by radiography. Hopson et al. [10]

found greater angles, probably generated by the differences in how anatomical reference points were marked. The SEM for the interrater agreement of 34.4° is high although in line with the low reproducibility. Probably, it could have been helpful to calculate the intrarater reproducibility of examiner MW as well and so identify possible examiner inconsistencies [20], which could explain the high value of the SEM of 34.4°. However, we decided to provide only the intrarater reliability of examiner HD. We chose this option to limit the time involvement of the participating runners. The total time for the measurements of one runner was about an hour, including the breaks in between. If the other examiner had taken the tests twice for every runner, the randomization schedule had to be adapted and probably runners had to spend more than two hours while being measured. Furthermore, the $SEM_{CONSISTENCY}$, which not included the systematic error [24], gave a value of 9.1° and is more in the line with the findings of the intrarater agreement of this study. So, the high $SEM_{AGREEMENT}$ (34.4°) of the interrater agreement is possibly based on a systematic error.

Sex difference

In our study a difference was found between male and female runners for the navicular drop and extension of the MTP1. No difference was found for the AJD between male and female runners.

In the studies of Allen et al. [26] and McKeon et al. [19] no difference was found for the ND between males and females. Allen et al. [26] reported only the ND values for the ACL-injured group (mean ND of 10.2 and 10.7 mm for female and males, respectively) and did the NDT measurement with a metrecom. In the study of McKeon et al. [19] a sex difference of 0.1 was found with a 95% confidence interval (CI) of –0.01 to 0.24 mm in a cohort of 118 healthy adults and used the same protocol (sitting to stand) as in our study. However, McKeon et al. [19] did the seating measurements in subtalar neutral position and measured the navicular drop with a straight edge ruler. This could explain the difference with our findings (mean differences of 1.8 mm and 95% CI of 0.6 to 2.9). But also the difference in age of the study population could explain the difference in findings. McKeon et al. [19] used a greater number of participants (57 male and 61 female volunteers) with a younger age (mean age of 21.1 ± 3.0 years and 20.0 ± 1.6 years for male and female, respectively) than in our study, with 22 males and 20 females runners (mean age of 39.1 ± 14.7 years and 37.2 ± 9.3 years for male and female, respectively). It is possible that with increasing age the difference in ND between male and female runners is increased and this may explain the difference in findings between McKeon et al. [19] and ours. Further research in runners, with a more reliable measurement tool is needed before sex differences in ND, as found in our study, can be used in the theoretical model for explaining the risk profile differences between male and female runners.

We found no other studies in the literature with regards to possible sex differences for the ND Single Limb-Stance, extension of the MTP1 and the AJD.

Caution is needed when using the results of the data of the NDT Single Limb-Stance and extension of the MTP1-test to estimate sex differences because of the low reproducibility of these two tests. This study has some limitations. First, the standardization of the NDT was not optimal. Concerning the NDT, in our protocol the sitting position was used as neutral position of the foot instead of palpating the talar head, so the ND could be determined directly and the measurement time was minimized. The measurement time of the protocol of the extension of MTP1-test [10] was optimized by refraining from using a tapeline and standardized step length. However, to guarantee standardization, it was ensured that all participants reached the maximal stretch of the MTP joint with an extended knee, so step length did not influence the MTP1 extension. It was deliberately chosen to deviate slightly from the existing protocols in the literature to optimize the performing speed of the tests and to facilitate test performance in practice. Given the fact that we were planning a large epidemiological study on risk factors for running injuries we needed tests that were relatively easy to administer (for logistical reasons).

Secondly, by the possibility of using one set of intra-rater results, the examiner consistency in our study was not optimal to determine. Future studies should include a minimal of two sets of intra-rater results so the degree of examiner consistency can be calculated and discussed.

Furthermore, in the review of Menz [35] was stated that the navicular drop was possibly influenced by foot length. Nielsen et al. [36] found that foot length had a significant influence on the navicular drop in both men and women and that this could have been incorporated in the measurement protocol.

Conclusion

The reliability of the NDT, AJD and MTP1 extension tests have not yet been established in healthy adult runners, even though this population is of particular interest for screening purposes. This study fulfils this need and demonstrates that AJD can be measured reliably in runners (ICC > 0.85) with good interrater agreement (SEM 2.4°–8.7°). Furthermore, we found no differences in AJD between female and male runners. In contrast, the NDT (both Stance and Single Limb-Stance) and the extension of the MTP1 in weight-bearing position had a moderate and low reliability.

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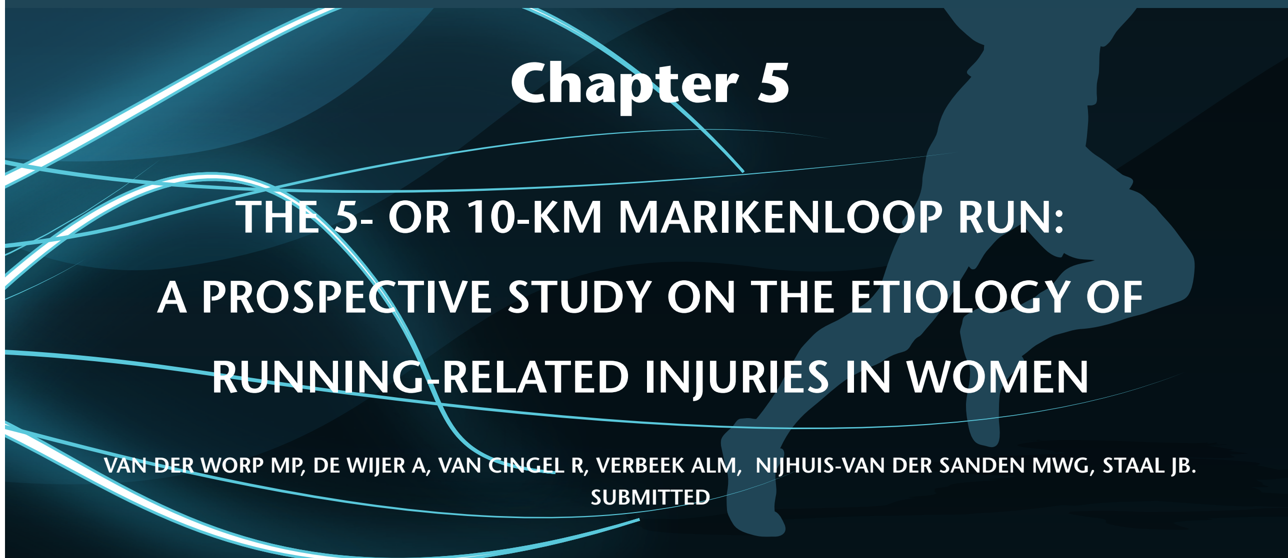

Chapter 5

THE 5- OR 10-KM MARIKENLOOP RUN: A PROSPECTIVE STUDY ON THE ETIOLOGY OF RUNNING-RELATED INJURIES IN WOMEN

VAN DER WORP MP, DE WIJER A, VAN CINGEL R, VERBEEK ALM, NIJHUIS-VAN DER SANDEN MWG, STAAL JB.
SUBMITTED

Abstract

Background: The popularity of running events is growing, especially in women. Until now, little is known about incidence and risk factors of running related injuries (RRIs) in female runners.

Objective: To determine the incidence and characteristics of RRIs and to identify risk factors of RRIs among female runners training for a 5- or 10-km race.

Study design: Prospective cohort study.

Participants: Of 13,500 women registered for the Marikenloop run of 5- or 10-km, 417 participated in this study.

Methods: Women were followed, 12 weeks, with questionnaires at baseline and after 4, 8 and 12 weeks. Furthermore, before the run, they completed two orthopedic tests; the navicular drop test and the extension test of the first metatarsophalangeal joint. RRI was defined as running-related pain of the lower back and/or the lower extremity that restricted running for at least one day.

Results: The 417 female runners reported 109 (26.1%) RRIs. The hip/groin, knee, and lower leg were most frequently mentioned injury sites. A multivariable Cox regression analysis showed that weekly training distance of more than 30 km (HR 3.28; 95% CI 1.23- 8.75) and a previous running injury, longer than 12 months ago (HR 1.88; 95% 1.03- 3.45), were associated with the occurrence of RRI.

Conclusion: The incidence of RRIs was similar in 5- and 10-km runners and non-participants. Only weekly training distance (> 30 km) and previous running injury (> 12 months) were associated with RRIs in female runners training for a 5- or 10-km race.

Introduction

Running is one of the most popular physical activities of adults worldwide, and many Western cities have their own recreational running events. Running is beneficial for general health[1], although the likelihood of sustaining a running-related injury (RRI) is high. Depending on the definition of RRI used, the type of runner investigated, the observation time, and the study design, incidence rates varying between 20% and 79% have been reported [2].

Although running has been popular since the 1970s,[3] the number of runners and running events have increased steadily since 2000 [4 5]. This is largely due to the increased number of girls and women who have started running[3 6]. Because women started later with running than men, there is a gap in the literature on the risk factors of RRI in women. Therefore, emphasis should be placed on research involving female runners because they have been under-represented, relative to male runners, in studies to date.

In a recent systematic review by Van der Worp et al.[7] some evidence was found that male and female runners have a different risk profile, although given the small number of studies that investigated the effect of runner's sex on RRIs, it was not possible to establish sex-specific profiles for risk factors.

Prospective cohort studies have identified four risk factors for RRI in female novice runners: lack of running experience[8], higher body mass index (BMI)[8], earlier participation in sports without axial pressure[8],and a larger navicular drop[9]. Furthermore, running once a week, age older than 50 years and running with 4- to 6-month-old shoes were identified as risk factors in female runners training for a 10-km race[10]. Macera et al.[11] additionally found running more than two thirds of the time on concrete to be a risk factor in female runners. The female participants of these studies were not specifically participating in a running event[11] nor were training under supervision (e.g. trainer, coach, etc.) to prepare for a specific event [8-10]. Runners who are being supervised are probably more likely to report injuries, thereby increasing the incidence of RRIs among coached/trained runners[12].

Little is known about predictors of RRIs in female runners preparing for a 5- or 10-km running event, combined with/without supervision. Therefore, risk factors found in female runners as stated above (running experience, BMI, other sports activity, navicular drop, age, previous running injury, shoe age and type of terrain) must be tested in this specific group of runners. Furthermore, we wanted to know if extension of the first metatarsophalangeal joint (MTP 1) is associated with RRI, because a restriction in the amount of the MTP1 extension range of motion can impair normal foot function[13] and increase the risk on RRI. At least, we were interested or exposure, defined as weekly running distance, was associated with RRI because training errors are often responsible for RRI[14].

This is the first study to specifically investigate only female runners, which is important given the increased female participation in running events[4]. Hence, the aim of this study was to determine the incidence and characteristics of RRIs, and risk factors, in female runners training for a 5- or 10-km race.

Materials and methods

Study design and participants

The aim of this prospective cohort study was to identify risk factors for injuries in female runners preparing for a 5- or 10-km race. The study sample size was calculated based on the assumption that there would be 7 events per indicator variable, an injury incidence rate of 25%, and 10 independent predictors, resulting in a required sample size of at least 300 participants[15].

Women, with an age of 18 years or older and who had signed up for the 'Marikenloop 2013' (held on 26 May) were eligible for inclusion. The Marikenloop is a run over 5- or 10 km and is a female-only event. All participants were informed about the study via social media and the newsletter of the 'Marikenloop' organization. They could register for study participation from 8–12 March 2013 (13,000 women had signed up for the event by 12 March). Participants were told that the purpose of the study was to identify risk factors for running injuries and that they would be followed up for 12 weeks, every 4 weeks: from 8 weeks before until 4 weeks after the Marikenloop. After they provided informed consent, they were given access to the baseline questionnaire via email. The study was approved by the Medical Ethics Committee of the Radboud university medical center, Nijmegen, the Netherlands.

Baseline Measurements

To determine potential risk factors for the occurrence of RRI in female runners in preparation for the present study a systematic review was conducted[7]. Baseline data were collected by means of a questionnaire covering personal and anthropometric information, past musculoskeletal injuries, past/current running routines, running-shoe characteristics and participating in other sports.

Open-ended questions were used to obtain self-reported data about age (day of birth), body height (cm) and body weight (kg). Body Mass Index (BMI) was calculated using the reported data for height and weight (BMI= weight [kg] divided by height^2 [m]). Information about where and when musculoskeletal injury of the lower extremity and lower back in the past was sustained was assessed using pictures of anatomical sites, with occurrence of injury being scored as none, < 3 months, 3-12 months, or > 1 year ago.

Multiple-choice questions were used to gather most information. Current running routine was divided into four categories (weekly distance run 0–10 km, 10–20 km, 20–30 km, >30 km) and previous running experience in three categories (<3 months, 3–12 months, >12 months). There were four categories of type of running surface (asphalt, tartan, wood, and/or sand), with a fifth open-ended category (other), divided into hard (asphalt, tartan, sidewalk, etc.), soft (wood ground, sand, etc.) or combination surfaces. Age of running shoe was classified into three categories (<3 months, 3–12 months, >12 months). Participation in sports, other than running, was assessed by using open-ended questions concerning type of sport. The various types of sports were categorized into axial loading (e.g. tennis, basketball, etc.) and non-axial (e.g. swimming, cycling, etc.) sports.

Physical tests

All participants were invited to undergo two physical tests to assess navicular drop and extension of the first metatarsophalangeal (MTP I) joint. The tests were performed in the 2 months prior to the Marikenloop on two separate occasions on Saturdays (13 April and 11 May 2013) and on the day of the Marikenloop (26 May 2013). The tests were performed by two experienced sports physical therapists and 33 physiotherapy students at the end stage of their study at the HAN University of Applied Sciences, Nijmegen, the Netherlands. All examiners had a training session of 2 hours with theoretical explanation, video tutorials, and practical exercise, with a qualification examination at the end, to obtain uniformity in test performance and optimize the interrater agreement.

The navicular drop indicates the level of foot pronation and was first described by Brody[16]. Palpation and marking the navicular tuberosity were done in long-sitting position with the feet in maximal dorsiflexion. The navicular drop was assessed by measuring the change in the height of the navicular tuberosity between sit, non-weight-bearing position (subtalar neutral) and standing, weight bearing with the subtalar joint in relaxed stance[17 18]. With the runner sitting in long sit, the MTP I joint was identified by passive dorsiflexion and plantar flexion of the hallux. Marks were made on the medial and ventral aspects of the joint center and, after palpation, on the medial side of the base of the shaft of the first metatarsal bone[13]. The static weight bearing step length (30 cm) position as described by Hopson [13] was used to measure the extension of the MTP I joint. A goniometer (MSD pocket goniometer, baseline 180 degree, transparent plastic) was used for the angle measurements and the results of the left and right sides were averaged and used as one cluster in the analyses.

Definition and assessment of RRI

In this study, RRI was defined as running-related pain of the lower back and/or the lower extremity that restricted running for at least one day[8]. Participants were asked, after 4, 8 and 12 weeks by e-mail, whether new musculoskeletal running injuries occurred of the lower back and/or the lower limb. They were asked to report the exact date the injury occurred or started. In case a RRI was reported but no date was given, the middle day of the four weeks was taken as occurrence date of the RRI. The date the injured participants started running again were also recorded as well as recurrent injuries. Participants were provided a manikin of the leg to indicate the location of the injury.

Analysis

Participants were excluded from the analyses when no follow-up questionnaire was filled out. Baseline characteristics for all potential risk factors were presented in numbers and as means and standard deviations for continuous variables.

The incidence of RRI was described as the percentage of injuries (including recurrences) in the entire group, in the 5-km runners, and in the 10-km runners, and for the group of runners who did not participate in the Marikenloop (NML).

The primary outcome of this study was the exposure time from the baseline measurement until the first RRI occurred. In case no RRI occurred during the entire 12 weeks follow-up period, exposure time was censored at 12 weeks. When participants were lost to follow-up and no RRI occurred, the exposure time was censored at the last follow-up time point for which data were available. All potential risk factors were first bivariately entered into a Cox regression analysis to examine the influence of these variables on the occurrence of RRI. Subsequently, all these potential risk factors were simultaneously entered into a multivariable Cox regression model.

The assumption of proportional hazards was evaluated by log-minus-log plots and tested with the goodness of fit[19]. When a runner had more than one injury during the 12 weeks period, the first RRI was used as event in the Cox regression analyses, both in the bivariate and in the multivariable analyses. Hazard ratios (HR) with corresponding 95% confidence intervals (CI) were reported. Possible risk factors with $P \leq 0.05$ were considered statistical significant. All analyses were performed using SPSS version 22.0 (SPSS Inc., Chicago, Illinois).

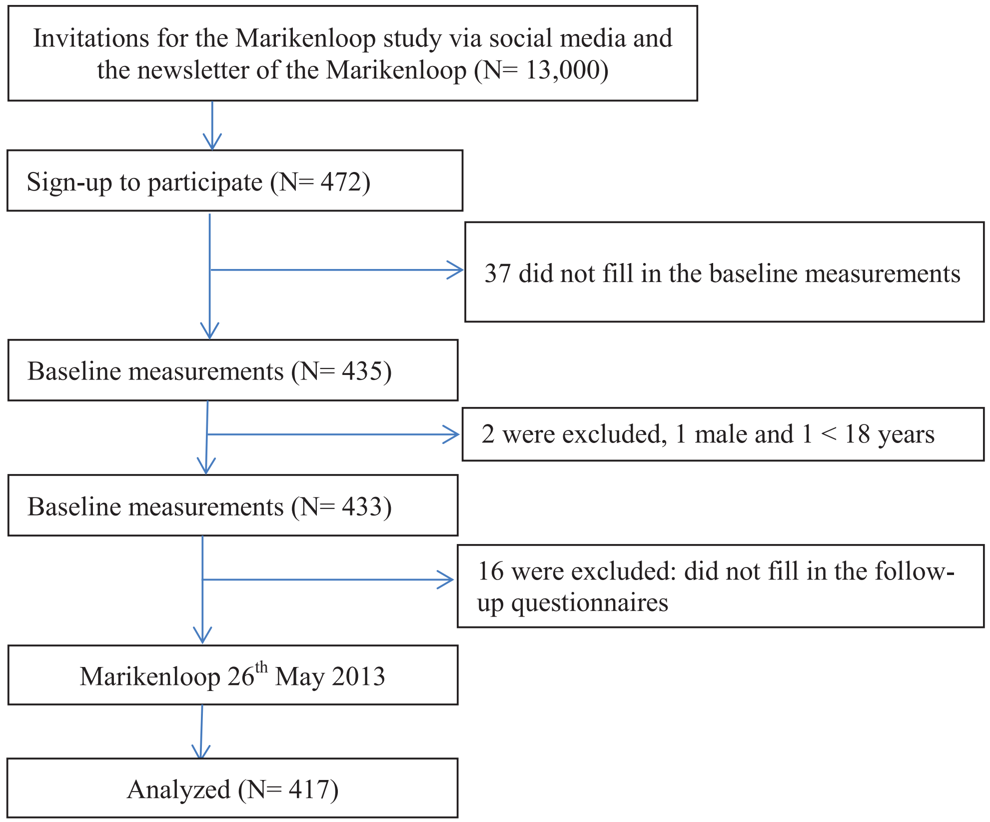

Figure 1 Participants flowchart.

Table 1 Baseline characteristics of all participants and both for the non-injured and injured participants.

Characteristics	Total Participants		Non-injured		Injured	
	N	Mean± SD	N	Mean± SD	N	Mean± SD
Marikenloop-run						
5 kilometer (5 km)	189		147		42	
10 kilometer (10 km)	184		145		39	
Did not run Marikenloop (NML)	44		32		12	
Age (years)	417	38.7± 11.5	324	39.0± 11.9	93	37.7± 10.2
< 40	212	29.0± 5.8	160	28.7± 5.8	52	31.1± 5.7
≥40	205	48.7± 6.2	164	49.1± 6.3	41	47.3± 5.6
BMI (kg/m^2)	417	23.2± 2.9	324	23.0± 2.9	93	23.8± 2.9
≤ 25	332	22.0± 1.8	263	21.9± 1.8	69	22.4± 1.8
> 25	85	27.5± 2.3	61	27.5± 2.3	24	27.6± 2.1
ND (mm)	307	6.3± 3.0	235	6.3± 2.9	72	6.3± 3.3
< 10	267	5.4± 2.0	207	5.5± 2.0	60	5.2± 2.2
≥ 10	40	12.0± 1.9	28	12.1± 1.8	12	11.8± 2.0
Extension MTP1-joint (degrees)	304	95.7± 12.6	233	95.4± 11.9	71	96.5± 14.7
Weekly running distance						
< 10 km p/w	186		145		41	
≥ 10- 20 p/w	150		120		30	
≥ 20- 30 p/w	62		46		16	
≥ 30 km p/w	19		13		6	
Previous RRI						
No injury	191		156		35	
< 3 months	43		33		10	
≥ 3- 12 ≤ months	87		65		22	
≥ 12 months	96		70		26	
How long running						
< 3 months	44		33		11	
≤ 3- 12 ≤ months	80		56		24	
> 12 months	293		235		58	
Other sports activity						
No	187		141		46	
Unloaded	35		29		6	
Loaded	195		154		41	
Type of terrain						
Soft	14		10		4	
Hard	184		140		44	
Combination	217		172		45	
Age running shoe						
< 3 months	86		66		20	
≥ 3- 12 ≤ months	186		144		42	
> 12 months	145		114		31	

Categorical data was presented as N and continuous data as means (SD).

BMI, body mass index; ND, navicular drop; MTP1, first metatarsophalangeal; RRI, running related injury.

Results

Participants

On 12 April 2013, 435 participants had completed the baseline questionnaire; 37 runners (8%) who had signed up for the study did not complete the baseline questionnaire. The average age of the two groups did not differ significantly (p=0.9). Two participants were excluded: one was a man and the other younger than 18 years. Thus 433 women were included in the study, of whom 417 (96%) completed at least one follow-up survey and 299 (69%) underwent all four physical tests. The flow of participants is shown in Figure 1.

Overall, 189 women (45%) ran 5 km and 184 (44%) ran 10 km; 44 (11%) did not take part in the race. The first follow-up questionnaire was completed by 410 runners (98.3%), the second by 407 (97.6%), and the third by 376 (90.2%). Seven runners (1.7%) did not complete follow-up questionnaires at 8 and 12 weeks follow-up.

The characteristics of the 417 female runners are presented in Table 1.

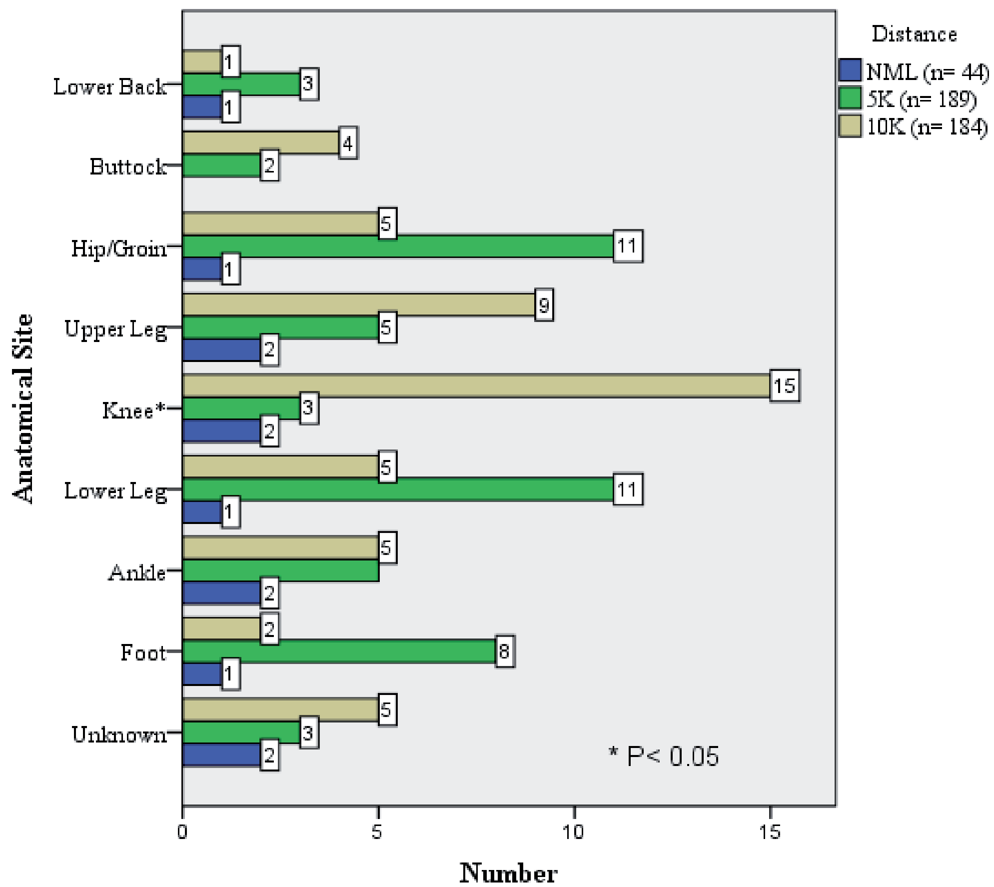

Figure 2 Body locations of running-related injuries in women who ran 5 km or 10 km or the non-participants who did not run the Marikenloop (NML).

Incidence & location of RRIs

A total of 109 (26.1%) RRIs were reported by 93 of the 417 runners during the 12-week follow-up period: 48 (25.3%) among 189 5-km runners and 49 (26.6%) among 184 10-km runners; 12 (27.3%) RRIs were reported by the 44 of the non-participants. Six (12.5%) of the injured 5-km runners reported 2 RRIs, 4 (66.7%) of which were recurrences of the same injuries; location and side. Ten (20.4%) of the injured 10-km runners each reported 2 RRIs, 3 (33.3%) of which were recurrences. All 12 non-participants reported 1 injury and so, no recurrences.

The location of the RRIs is shown in figure 2. The hip/groin region and the lower leg were the most common sites of injury in the 5-km runners (both 11 of 51), and the knee was the most common site of injury in the 10-km runners (15 of 51). In the non-runners group (NML), the most common sites of injury were the upper leg, knee, and ankle.

The only significant difference between the two groups of runners was the number of knee injuries: 3 (2.9%) in the 5-km group and 15 (14.9%) in the 10-km group.

Risk factors for RRI

After four weeks, in 9 cases a RRI was reported but no date was given and the middle day of the four weeks was taken as occurrence date of the RRI. Results of the bivariate and multivariable analyses are presented in Table 2.

In the bivariate analyses BMI (HR 1.08; 95% CI 1.01- 1.15; p= 0.02) was significantly related to RRI. A weekly running distance of ≥ 30 km (HR 3.28; 95% CI 1.23- 8.75; p= 0.02) and a previous RRI of ≥ 12 months ago (HR 1.88; 95% 1.03- 3.45; p= 0.04) were significantly associated with the occurrence of RRI in the multivariable analysis.

Discussion

The purpose of this prospective cohort study was to determine, in women training for a 5- or 10-km race, the incidence and characteristics of RRIs and to identify specific predictors of these injuries. We found an overall RRI incidence of 26.1%. Compared with the 5-km runners, the 10-km runners had more knee injuries. Risk factors for RRI's were a weekly training distance (> 30 km) and a previous running injury (> 12 months ago).

Incidence & characteristics of RRIs

The incidence of RRI found in this study (25.3–26.6%) was lower than that reported in other studies of female runners (28.7–79.1%)[10 20-22]. This difference might be due to differences in study population, follow-up time and in definition of RRIs used. In most studies, the runners participated in a training program[10], were running a marathon[22], and/or were track and field athletes[21]. In our study, participants had only to register for a 5- or 10-km race, which means that our study population was probably more diverse and less supervised by a trainer/coach/etc., in terms of training. A previous study[20] reported a higher incidence of injury among supervised runners, possibly because they had more opportunity to report injury[12] in combination with a longer follow-up period: 6 months vs. 12 weeks in our study. In contrast with this and other studies[10 20 21], Macera et al. reported a lower incidence of RRIs (15.8%) in woman participating in a 5- or 10-km race [22]. The difference may be due to the study design: Macera et al.[22] carried out a cross-sectional study, with only one questionnaire completed a month after the race, whereas the present study and other studies had a prospective longitudinal-design.

Our findings regarding the site of RRIs are in agreement with the literature. The knee was the site of most injuries overall and in the 10-km runners, whereas the lower leg and hip/groin were the commonest sites of injury in the 5-km runners. The same distribution pattern was reported by Buist et al.[8] for female runners during preparation for a 4-mile recreational running event.

Table 2 Results of the bivariate and multivariable Cox regression analyses for overall RRIs.

Characteristic	Bivariate analysis			Multivariable analysis		
	HR	95% CI	P-value	HR	95% CI	P-value
Age (years)	0.99	0.97- 1.01	0.33	0.98	0.96- 1.00	0.06
BMI (kg/m^2)	1.08	1.01- 1.15	0.02*	1.05	0.96- 1.14	0.28
ND (mm)	1.00	0.93- 1.08	0.98	1.00	0.92- 1.09	0.99
Extension MTP1-joint (degrees)	1.01	0.99- 1.03	0.49	1.00	0.98- 1.02	0.81
Weekly running distance (ref.= < 10 km p/w)						
≥ 10- 20 p/w	0.88	0.55- 1.41	0.60	0.90	0.48- 1.67	0.73
≥ 20- 30 p/w	1.18	0.66- 2.10	0.58	1.92	0.91- 4.07	0.09
≥ 30 km p/w	1.48	0.63- 3.49	0.37	3.28	1.23- 8.75	0.02*
Previous RRI (ref.= no injury)						
< 3 months ago	0.64	0.39- 1.07	0.09	1.36	0.58- 3.20	0.47
≥ 3- 12 ≤ months	0.85	0.41- 1.77	0.67	1.23	0.64- 2.36	0.54
≥ 12 months ago	0.93	0.53- 1.63	0.79	1.88	1.03- 3.45	0.04*
How long running (ref.= < 3 months)						
≤ 3- 12 ≤ months	1.18	0.58- 2.42	0.64	1.44	0.54- 3.83	0.46
> 12 months	0.74	0.39- 1.42	0.37	0.98	0.38- 2.51	0.97
Other sports activity (ref.= no other sports)						
Unloaded	1.21	0.80- 1.85	0.37	0.64	0.24- 1.69	0.36
Loaded	0.82	0.35- 1.93	0.65	0.70	0.42- 1.15	0.16
Type of terrain (ref.= soft)						
Hard	0.78	0.28- 2.17	0.63	0.83	0.24- 2.85	0.77
Combination	0.67	0.24- 1.86	0.44	0.64	0.19- 2.17	0.47
Age running shoe (ref.= < 3 months)						
≥ 3- 12 ≤ months	1.08	0.62- 1.89	0.79	1.36	0.69- 2.69	0.37
> 12 months	1.08	0.68- 1.71	0.76	1.85	0.89- 3.83	0.10

*** Significant (p≤ 0.05)**

BMI, body mass index; ND, navicular drop; MTP1, first metatarsophalangeal; RRI, running related injury; Ref., reference.

Risk factors of RRIs

High weekly running distance is associated with an increased risk of sustaining RRI [2 14 23]. This trend was also seen in a prospective study of 12 month in habitual female runners[11] and was also found in the specific group of runners of our study; females preparing for a 5 or 10 km run. Therefore, it seems that the musculoskeletal system cannot adapt to the high weekly running distance, which made the runner vulnerable to RRI's[24].

Furthermore, a post hoc analysis (χ^2) of our study showed that the female runners preparing for the 5 km had a lower weekly running distance than those preparing for the 10 km race ($p \leq 0.05$). However, the number of runners in both groups was too small to identify distance specific risk factors in our study.

In the recent systematic reviews of Van der Worp et al.[7] and Saragiotto et al.[25], a previous injury was identified as sole risk factor for RRI. Our study is the first which confirms these findings specifically for female runners[7]. It is not clear whether a high rate of re-injury is due to incomplete healing of the original injury, an uncorrected biomechanical problem, or recall bias and/or the definition of the injury[7]. However, with the consistent finding of this risk factor in different study populations it seems, in daily practise, very useful to prevent re-occurrence of RRI. Combining a personal injury history with a specific training and exercise program by sports physician and/or physical therapist to optimize the loading of the previously injured tissue seems important in this prevention.

Strengths and limitations

Major strengths of this study are the prospective study design, the large cohort of more than 400 runners and the specific group of runners; only female, preparing for a 5- or 10 km race event. There were, however, some limitations. First, we used self-reported injuries because the logistics of this study did not allow for confirmation of the diagnosis by sports physicians and/or sports physical therapists. Secondly, the follow-up was for practical and financial reasons 12 weeks and may have been too short to establish the risk profile of 5- and 10-km runners.

Conclusion

In conclusion, a better apprehension of risk factors for RRIs in women participating in running events would enable targeted prevention strategies. This study shows that training distance and previous running injury may have a possible role in preventing RRI. More prospective research, with a large group of runners and detailed description of running exposure, is needed to confirm our findings, especially among female event runners. These runners form a large group and should be encouraged to continue running, without injury, to generate health benefits in the long term.

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Chapter 6

NUTRITIONAL INDICATORS FOR GASTROINTESTINAL SYMPTOMS IN FEMALE RUNNERS: THE ‘MARIKENLOOP STUDY’

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Abstract

Objectives: Among runners the reported prevalence of exercise-induced gastrointestinal (GI) symptoms is high (25%–83%). We aimed to investigate the prevalence of GI symptoms in women during a 5–10 km run in general and to explore the association between nutritional intakes and GI symptoms.

Setting: As part of the Marikenloop-study (a cohort study to identify predictor variables of running injuries), a cross-sectional questionnaire was distributed in interested runners of the '2013 Marikenloop'.

Participants: 433 female runners filled in the questionnaire.

Primary and secondary outcome measures: The primary outcome measure was the frequency of running-related GI symptoms during running in general and during the last (training) run. Furthermore, dietary intake was determined before and during this run. Secondary outcome measures were several demographic and anthropometric variables.

Results: During running in general, 40% of the participants suffered from GI symptoms and during their last run, 49%. The GI symptoms side ache, flatulence, urge to defecate and regurgitation and/or belching were most commonly reported. Lower age (OR=0.98, 95% CI 0.96 to 1.00), minor running experience (OR=3.1, 95% CI 1.7 to 5.7), higher body mass index (OR=1.1, 95% CI 1.0 to 1.2), consuming carbohydrate-containing drinks during running (OR=10.5, 95% CI 1.4 to 80.3) and experiencing GI symptoms during running in general OR=5.0, 95% CI 3.2 to 7.8) significantly contributed to GI symptoms during the last run in the logistic regression analysis. In contrast, time of eating and carbohydrate-containing drinks consumed prior to the run were not related to GI symptoms.

Conclusions: In conclusion, the current study confirms the high prevalence of GI symptoms in female runners. Several predictor variables contributed to the GI symptoms but more research is needed to specify the effects of prerunning eating and carbohydrate containing drinks on GI symptoms during running.

Introduction

Emerging research indicates that physical activity is beneficial for the gastrointestinal (GI) tract.[1–3] However, strenuous physical exercise such as running can also induce upper and lower GI tract symptoms.[1–3] Prevalence of exercise-induced GI symptoms in runners has been reported to vary from 25% to 83% during or after a run.[14–13]

Exercise-induced GI symptoms seem to be caused predominantly by increased sympathetic nervous system activity that redistributes blood flow during exercise from the splanchnic organs to the working skeletal muscles, heart, lung and brain.[1 14] This often leads to GI ischaemia, which may result in GI symptoms.[1 15] GI symptoms are more likely to occur in runners as compared with cyclists or swimmers[9 11 13 16 17] probably because of the constant pounding motion of running, which may induce stress to the abdominal organs.[16] Therefore, GI symptoms might be a reason for people to quit running.[7]

In the past decades more women have started running in the Netherlands.[18] In several investigations, a higher incidence of running-related GI problems was observed in women compared with [15–9 12] men. Therefore, GI symptoms may become an increasing problem.

The occurrence of exercise-related GI symptoms may further be higher with lower age,[6 10] less running experience,[7 10] longer duration of exercise[6 8 19] and an increased BMI.[20]

Several possible dietary factors have been hypothesised as inducing GI symptoms in athletes. For example, dehydration,[8 21 22] high fat, fibre and protein intakes (solid food), eating before exercise and hypertonic solutions.[13] However, data on the association between exercise induced GI symptoms and prerunning eating and/or hypertonic solutions are scarce.

The American College of Sports Medicine stated that the pre-exercise meal should be consumed 3–4 h before exercise and a smaller meal or snack should be consumed 2–4 h before exercise.[23] However, minimal research has been performed on the effect of the timing of the pre-exercise meal and snack on GI symptoms. In 1989, Rehrer et al[8] found no association between the time of the last meal and GI disturbances, but almost all athletes ate 3–5 h before the race. They further showed that individuals who consumed solid food closer to the start vomited more frequently or had a higher vomiting urge during a triathlon.[13]

Another study also found that nausea exacerbated when exercise was conducted immediately after eating.[24] Rehrer et al[13] also showed that individuals who consumed hypertonic beverages had to vomit more and/or had stomach cramps. van Nieuwenhoven et al[16 25] found conflicting evidence about the effect of isotonic sports drinks compared with water on incidences of GI symptoms and GI variables. Peters et al[7] found that water intake before competition was related to more upper GI symptoms. It is not clear what amount of fluid or sugar contributes to GI symptoms.

The objective of this study was to investigate the prevalence of upper and lower GI symptoms in general during running and during the last run in female athletes who participated in the '2013 Marikenloop', a run of 5 and 10 km for women in the Netherlands. Furthermore, we aimed at exploring the association between the dietary intake of female runners' prerunning and GI symptoms during running.

Methods

Subjects

Study participants consisted participants aged ≥18 years who registered for the '2013 Marikenloop', a run specifically for women, which was held on 26 May 2013 in Nijmegen, the Netherlands. On 12 March, 13 000 women signed up for the '2013 Marikenloop', which is the largest run of the Netherlands for women with distances of either 5 or 10 km. Via social media and the newsletter of the 'Marikenloop' organisation, female runners were informed about the Marikenloop study. The runners from the '2013 Marikenloop' could sign up for the Marikenloop study online from 8 to 24 March. All participants first signed the informed consent. Participants were informed that the objective of the research was to identify predictor variables for running injuries.

Study design

The present study was part of the 'Marikenloop study', which is a prospective cohort study aimed at identifying predictor variables for running injuries. To arrive at the study sample size we assumed 8 events per variable, an injury incidence rate of 30% and 15 independent predictors resulting in a required sample size of at least 360 participants.[26 27] The study also consisted of a crosssectional questionnaire to obtain data on GI symptoms and dietary information, as well as several demographic and anthropometric data. The questionnaire was distributed via email on 24 March. Participants received two reminders if needed and were allowed to complete the questionnaire until 12 April 2013.

Questionnaire

From the total online questionnaires, several demographic and anthropometric characteristics and questions about running were used for the present study. Furthermore, questions were developed about the presence of GI symptoms and a dietary recall in which the timing of the prerunning meal and snack and of drinking around the last run was detected.

The participants were asked to estimate their frequency of running-related GI symptoms during running in general by indicating on a four-point Likert scale whether symptoms generally occurred either never, sometimes, occasionally or frequently during running. Symptoms surveyed included the upper GI tract symptoms of chest pain, nausea, regurgitation and/or belching, heartburn, feeling of fullness and vomiting. The lower GI tract symptoms questioned were bloating, abdominal cramps, flatulence, urge to defecate, diarrhoea, constipation and rectal bleeding and/or haematuria. Side ache was also included as a lower GI symptom.[8]

Participants were then asked to indicate the presence of these 14 GI symptoms (yes/no) during their last run in which they prepared for the 'Marikenloop' around 2 months before the actual 'Marikenloop' run. Furthermore, participants were asked what the time interval between their last food intake before the start of their last run was. It was possible to indicate that they had run on an empty stomach in the morning.

Drinking habits around the last run were inquired by asking what the participants drank before their last run. For several sport drinks, pictures were used and for soda, juices, alcoholic drinks and with the option 'other drinks' a clarification was asked to indicate which drink it was exactly. Per drink, participants were asked when they drank it (1–4 h before running, within 1 h before running, during running, within 1 h after running, 1–4 h after running). Finally, participants had to estimate how much they drank in these five time frames. Pictures were used to indicate what normal portion sizes of different glasses and bottles are. Carbohydrate content of the various beverages that were consumed was determined using manufacturers' specifications. A drink was considered hypotonic if it consisted of maximal 6 g/100 mL carbohydrates. If the drink consisted of 6–8 g/100 mL carbohydrates, it was considered isotonic and with more than 8 g/100 mL carbohydrates, it was called hypertonic.[28] If hypotonic and hypertonic drinks were drunk at a specific time frame, the drink was rated as isotonic. When an equal amount of hypotonic and isotonic drinks or isotonic and hypertonic drinks was consumed simultaneously, the highest category was chosen. If however, one of two sorts of drinks was consumed more at a specific time frame, that category was chosen (eg, if two hypotonic and one isotonic drink was consumed in the same time frame, hypotonic was chosen).

Data analysis

Statistical analysis was performed using SPSS for Windows (V.19.0; SPSS Inc, Chicago, Illinois, USA). and a GI symptom was considered present during running in general (a positive response) when a participant answered 'occasionally' or 'frequently' to the question about the frequency of GI symptoms during running. A GI symptom was considered absent (a negative response) when 'never' or 'sometimes' were indicated. GI symptoms were considered present during the last run when participants indicated 'yes' for a symptom on the list.

Analysis of normal distribution (Shapiro–Wilk test and normal QQ-plot) was performed for continuous variables: age, BMI, timing of pre-running meal and/or snack, amount of drink (mL) and by dividing the selfmeasured waist circumference (cm) with the reported height (cm), the waist-to-hip ratio (WHR) was obtained.

Mean baseline differences between participants with and without GI symptoms were determined using an independent samples t-test to detect possible confounders.

To compare characteristics between the runners with and without GI symptoms during their last run two sample t tests were performed for continuous variables.

In terms of categorical variables χ^2 tests or a Fisher's exact test were conducted.

Significant associations were identified with multivariable binary logistic regression analysis (forced entry method). Nutritional variables (ie, timing of the prerunning meal/snack, running on an empty stomach, amount drink (mL) consumed and type of drink) were hypothesised to be related to GI symptoms during the last run and possible confounders were adjusted for in the model. To check for collinearity between the different predictor variables we calculated the variance inflation factors (VIF). If multicollinearity was present the variable which was considered most relevant, was used in the multivariable analyses. Risk model calibration was assessed by the Hosmer Lemeshow goodness-of-fit test. p Values$\leq$0.05 were accepted as statistically significant.

Results

Subjects

On 12 April, 435 of the 472 participants filled out the baseline questionnaire of the 'Marikenloop study' (drop-out rate: 8%). The average age of the drop-out group was 38.4±12.4 (SD) and did not significantly differ from the group who filled out the questionnaire (p=0.90). Two questionnaires were excluded because the participant was male (n=1) and not >18 years old (n=1).

The baseline characteristics of the included 433 participants are presented in table 1. The total group had an average body mass index (BMI) of 23.2 kg/m^2 and a WHR of 0.80. Two hundred and ten participants sustained ≥1 GI symptom during their last run. Significant differences between the groups with and without symptoms during their last run were found for age, body weight and BMI.

Table 1 Baseline characteristics of the Marikenloop runners

Variable	Total group n=433*	≥1 GI symptoms during their last run: Yes n=210*	No n=223*
Age (year)†	38.6±11.5	36.8±11.5	40.4±11.2
Body weight (kg)†	67.0±10.6	68.8±12.3	65.3±8.5
Height (cm)	169.8±6.3	170.1±6.6	169.5±5.9
BMI (kg/m^2)†	23.2±2.9	23.6±3.0	22.7±2.7
Waist circumference (cm)	79.7±7.9‡	80.6±7.7§	79.0±8.1¶
WHR	0.80±0.06‡	0.81±0.05§	0.80±0.06¶

*Data represent mean±SD.
†Significant difference between group with and without GI symptoms during their last run (p<0.001).
‡n=245.
§n=109.
¶n=136.
BMI, body mass index; GI, gastrointestinal; WHR, waist-to-hip ratio.

GI symptoms

The total prevalence of experiencing at least one GI symptom during running in general was 40%, while 49% of the participants experienced at least one GI symptom during their last run (p=0.00; see table 2). Fifty-four per cent who had GI symptoms during running in general experienced more than one symptom. During the last run, this percentage was 42%. As shown in table 2, during running in general, significantly more lower GI symptoms occurred than upper GI symptoms (0.36 (0.31 to 0.40), 0.16 (0.12 to 0.19), respectively) just like during the last run (0.42 (0.37 to 0.46), 0.19 (0.15 to 0.23), respectively). For all GI symptoms, except 'urge to defecate' and 'constipation', more participants suffered from these symptoms during their last run than during running in general (see figure 1). Significant

Table 2 Prevalence of at least 1 GI symptom during running in general and during their last run

	≥1 GI symptoms*		≥1 upper GI symptoms		≥1 lower GI symptom*	
	n	Pr (95% CI)	n	Pr (95% CI)	n	Pr (95% CI)
During run in general	171	0.40 (0.35 to 0.44)	67	0.16 (0.12 to 0.19)	155	0.36 (0.31 to 0.40)
During last run	210	0.49 (0.44 to 0.53)	82	0.19 (0.15 to 0.23)	181	0.42 (0.37 to 0.46)

*Significant difference between during run in general and during last run (p=0.00).
GI, gastrointestinal; Pr, prevalence.

differences between running in general and the last run were found for 'chest pain', 'vomiting' and 'rectal bleeding and/or haematuria' (p≤0.05). The most reported GI symptoms were 'side ache', 'flatulence', 'urge to defecate' and 'regurgitation and/or belching' for running in general and the last run.

Eating and drinking habits before and during last run

Forty-six women (11%) ran during their last run on empty stomach. The other participants (n=387) ate their prerunning meal 103.5±69.9 min (range 5–360 min) before the run. A snack was consumed 85.3±62.9 min (range 5–270 min) before the run (n=250). As shown in figure 2, most drinks consumed were hypotonic drinks, a few drank isotonic drinks and hypertonic drinks were the least popular. Most participants drank 1–4 h before running (70%). Within 1 h before running, 63% drank something. During their run only a few participants drank something (10%). Between 1and 4 h before their run 279.4±234.0 mL was consumed, within 1 h before the run 151.7±114.5 mL and during 28.2±87.5 mL.

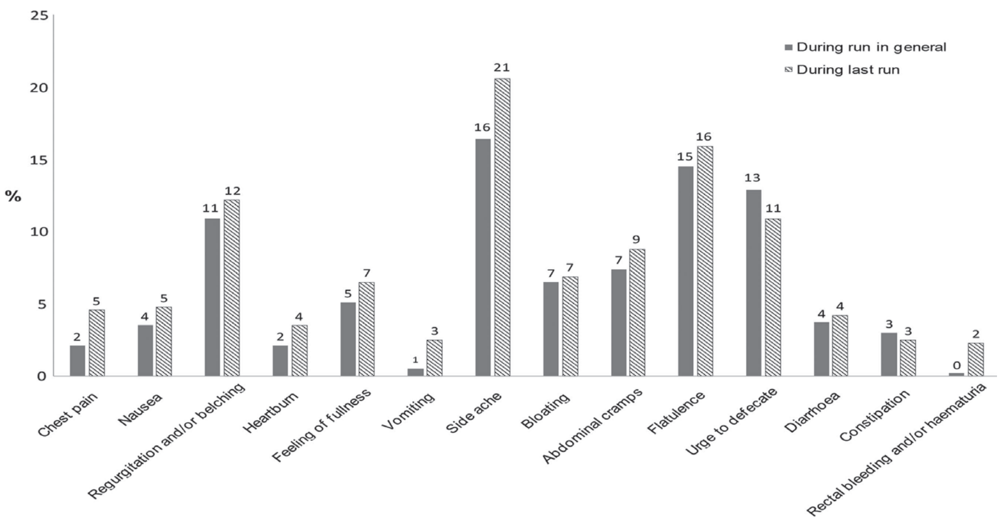

Figure 1 Participants who reported gastrointestinal (GI) symptoms during running in general and GI symptoms during their most recent run (%). Dark bars represent the percentage during running in general with a positive response (sum of 'occasionally' and 'frequently' responses divided by the total number of responses). Striped bars represent the positive response 'yes' divided by the total number of responses during the most recent run.

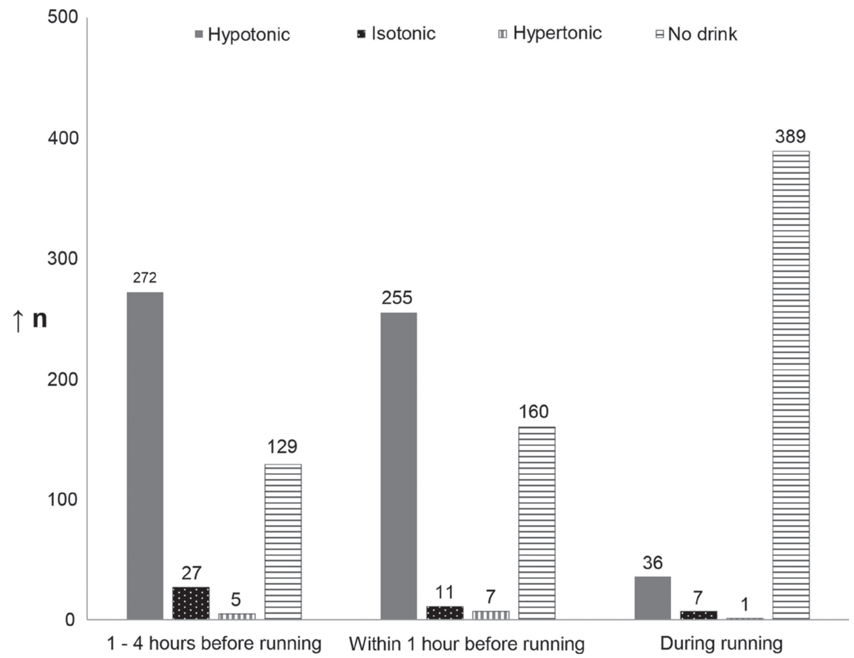

Figure 2 Sort of drinks consumed prior and during most recent run (n).

Risk indicator analyses

Female runners who experienced at least one GI symptom during their last run had a significantly lower age of on average 3.6 years, an on overage 0.9 higher BMI, included 37% more participants who experienced GI symptoms in general and had less running experience in months (p=0.00) than participants without GI symptoms (see table 3). From the eating-related variables and drinking-related variables, female runners with symptoms drank on overage 47.9 mL more 1–4h before running (p≤0.05) and running on an empty stomach was correlated with GI symptoms during the last run. From the group who experienced GI symptoms, less people ran on an empty stomach than the group without GI symptoms during their last run (p=0.023). Isotonic and hypertonic drinks and 30–40km a week and >40 km per average week were pooled, because counts were <10.

Multivariable logistic regression

Multicollinearity was present between the possible predictors of upper and lower GI symptoms and total GI symptoms in general. Since GI symptoms in general include upper and lower GI symptoms, this variable was evaluated, next to all the other predictor variables, by multiple logistic regression analyses (see table 4). The drinking of isotonic and/or hypertonic drinks compared with no drinks during running proved to have the largest positive predictive value for running-related GI symptoms and was associated with 10.5-fold increased odds of developing GI symptoms during the last run (95% CI 1.4 to 80.3). The prevalence of GI symptoms in general showed an odds of 5.0 (95% CI 3.2 to 7.8). Furthermore, a running experience of 3–12 months compared with more than 12 months increased the odds by 3.1 (95% CI 1.7 to 5.7). A higher age was slightly protective for suffering from GI symptoms during the last run (OR=0.98, 95% CI 0.96 to 1.0). Finally, a higher BMI of 1 unit was associated with GI symptoms during the last run (OR=1.1, 95% CI 1.0 to 1.2).

Table 3 Comparisons between female runners with or without GI symptoms regarding nutritional and activity features

Variable	≥1 GI symptoms during their last run: Yes n=210*	No n=223*	Test statistic	p Value
Age (year)	36.8±11.5	40.4±11.2	3.32†	0.00
BMI	23.6±3.0	22.7±2.7	−3.13†	0.00
Timing of prerunning meal (min)‡	104.6±69.8	102.4±70.3	−1.32†	0.19
Timing of prerunning snack (min)§	89.2±65.2	81.6±60.6	−0.48†	0.63
Amount drink (mL)				
1–4 h before running	304.0±263.7	255.0±200.1	−2.19†	0.03
Within 1 h before running	156.5±118.8	146.6±110.5	−0.90†	0.37
During running	27.5±83.0	28.7±91.6	0.15†	0.89
Running on an empty stomach (n)	15 (7%)	31 (14%)	5.20¶	0.02
Sport drink (n)				
1–4 h before running				
No drink	63 (30%)	66 (30%)	0.03¶	0.98
Hypotonic	132 (63%)	140 (63%)		
Isotonic and hypertonic	15 (7%)	17 (8%)		
Sport drink (n)				
Within 1 h before running				
No drink	75 (36%)	85 (38%)	2.63¶	0.27
Hypotonic	123 (59%)	132 (59%)		
Isotonic and hypertonic	12 (6%)	6 (3%)		
Sport drink (n)				
During running				
No drink	188 (90%)	201 (90%)	2.50**	0.29
Hypotonic	16 (8%)	20 (9%)		
Isotonic and hypertonic	6 (3%)	2 (1%)		
Prevalence of total GI symptoms in general (n)	123 (59%)	48 (22%)	62.12¶	0.00
Prevalence of upper GI symptoms in general (n)	52 (25%)	15 (7%)	26.90¶	0.00
Prevalence of lower GI symptoms in general (n)	109 (52%)	46 (21%)	46.04¶	0.00
Running experience (n)				
<3 months	26 (12%)	20 (9%)	21.43¶	0.00
3–12 months	57 (27%)	25 (11%)		
>12 months	127 (61%)	178 (80%)		
Kilometres ran in an average week (n)				
<10 km a week	103 (49%)	94 (42%)	2.77¶	0.43
10–20 km a week	72 (34%)	82 (37%)		
20–30 km a week	28 (13%)	35 (16%)		
>30 km a week	7 (3%)	12 (5%)		
Aim for '2013 Marikenloop' (n)				
5 km	91 (43%)	98 (44%)	0.02¶	0.90
10 km	119 (57%)	125 (56%)		

*Data represent mean±SD or n (%).
†Test statistic for independent samples t-test.
‡n=387.
§n=250.
¶Test statistic for χ^2 test.
**Test statistic for Fisher's exact test.
BMI, body mass index; GI, gastrointestinal.

Discussion

In runners exercise-induced GI symptoms are a problem. In this study 40% suffered from GI symptoms during running in general and the prevalence during the last run was 49%. The GI symptoms 'side ache', 'flatulence', 'urge to defecate' and 'regurgitation and/ or belching' were most commonly reported. Lower age, more running experience, higher BMI, consuming carbohydrate-containing drinks during running and prevalence of total GI symptoms during running in general were significantly related to GI symptoms during the last run.

Table 4 Predictor variables in the multivariable logistic regression model estimating the probability of GI symptoms in female runners during their run

Variable	GI symptoms OR (95% CI)	p-Value
Age (year)*	0.98 (0.96 to 1.00)	0.03
BMI (per 1 unit)*	1.12 (1.03 to 1.22)	0.00
Timing of prerunning meal (min)	1.00 (1.00 to 1.00)	0.59
Timing of prerunning snack (min)	1.00 (1.00 to 1.00)	0.75
Amount drink (mL)		
1–4 h before running*	1.00 (1.00 to 1.00)	0.20
Within 1 h before running	1.00 (1.00 to 1.00)	1.00
During running	1.00 (0.99 to 1.00)	0.23
Running on an empty stomach (n)*	0.59 (0.25 to 1.35)	0.21
Sport drink (n)		
1–4 h before running		
No drink	1	
Hypotonic	0.60 (0.34 to 1.07)	0.08
Isotonic and hypertonic	0.41 (0.15 to 1.11)	0.08
Sport drink (n)		
Within 1 h before running		
No drink	1	
Hypotonic	0.75 (0.43 to 1.31)	0.31
Isotonic and hypertonic	1.54 (0.46 to 5.14)	0.48
Sport drink (n)		
During running		
No drink	1	
Hypotonic	1.32 (0.46 to 3.74)	0.61
Isotonic and hypertonic	10.47 (1.37 to 80.34)	0.02
Prevalence of total GI symptoms in general (n)*	4.97 (3.15 to 7.84)	0.00
Running experience (n)*		
<3 months	1.62 (0.74 to 3.58)	0.23
3–12 months	3.09 (1.66 to 5.74)	0.00
>12 months	1	
Kilometres run in an average week (n)		
<10 km a week	1.37 (0.42 to 4.52)	0.60
10–20 km a week	1.26 (0.38 to 4.10)	0.71
20–30 km a week	1.24 (0.36 to 4.25)	0.73
>30 km a week	0	
Aim for '2013 Marikenloop' (n)		
5 km	1	
10 km	1.30 (0.80 to 2.11)	0.30

*p<0.05 in bivariate analyse.
BMI, body mass index; GI, gastrointestinal.

We found that 40% of the female runners suffered from GI symptoms during running in general. This is slightly lower than earlier reported prevalences of GI symptoms during running in general (between 50% and 54%).[4 7 11] Several articles detected the prevalence of GI symptoms at a specific run, which varied between 25% and 52%.[5 8 10 12 13] In accordance with these numbers, our participants indicated that during their last run 49% experienced GI symptoms. The higher amount of experienced GI symptoms during the most recent run compared with running in general might be caused by survey and recall bias.

It has been suggested that the distance of a run influences the prevalence of GI symptoms.[6 8 29] The exact distances of the last run were not detected in our study but no difference was found between women who were training for a 5 or 10 km run on the day of the 'Marikenloop'. However, the mentioned GI symptoms in the articles are quite severe and might occur more during a longer run and therefore may not be very prevalent in our participants. The protective effect of higher age shown in table 4 on GI symptoms has been reported previously.[6 9 10 30] In younger people more splanchnic vasoconstriction occurs because of more or a better response to catecholamines. This leads to reduced oxygen supply, which may result in GI symptoms.[1 10 15 22 30] Also, higher age is often accompanied with more running experience.[8 31] This association between running experience and less GI symptoms was found in several studies,[7 9 10 32] and corresponds with our results although we should be cautious since no linear relationship was found.

This study showed that with a higher BMI was associated with more exercise-induced GI symptoms. This corresponds with a meta-analysis showing that some GI symptoms are more strongly associated with obesity and increasing BMI than other GI symptoms.[20]

The timing of the prerunning meal and snack was not associated with GI symptoms (see tables 3 and 4). On average our participants consumed their food at least 1.5 h before exercising while other studies showed GI symptoms were only present when eaten within 30 min before exercising.[13 24]

We expected to see an association between isotonic and hypertonic sport drinks and GI symptoms, but this was only found when participants drank isotonic and/or hypertonic drinks during the run. This might be due to the fewer number of participants who drank isotonic and hypertonic sport drinks, which make it difficult to draw strong conclusions. There are, however, several mechanisms described that indicate that carbohydrate containing beverages can lead to reactions in the stomach and intestine which may result in GI symptoms. [1 13 16 30 33 34]

One should keep in mind that comparison with data of other surveys is difficult, because of the different answer options used for detecting GI symptoms and other interpretations of those answers. Another limitation was that the distances of the last runs in our study were not detected, except for the distance in the 'Marikenloop' they were training for. Furthermore, it would have been interesting to assess the associations between the predictors and the GI symptoms separately since some predictors will influence, for example, diarrhoea but not chest pain. The internet-based questionnaire has several other limitations. First, it was not validated since no short validated questionnaires for this purpose could be found. Also, it relied on the participant's memory and was therefore bias sensitive. The questions were preprogrammed, so participants could not freely tell their stories. An internet-based questionnaire is, however, low-threshold and user-friendly, which resulted in a high response (92%) and missing values were prevented.

In conclusion, the current study demonstrates that 40% of 433 female runners training for a 5 or 10 km run suffered from GI symptoms during running in general and 49% had ≥1 GI symptom during their last run. Predictor variables for experiencing GI symptoms during a run included lower age, less running experience, higher BMI, consuming carbohydrate-containing drinks during running compared to no drinks and experiencing GI symptoms during running in general.

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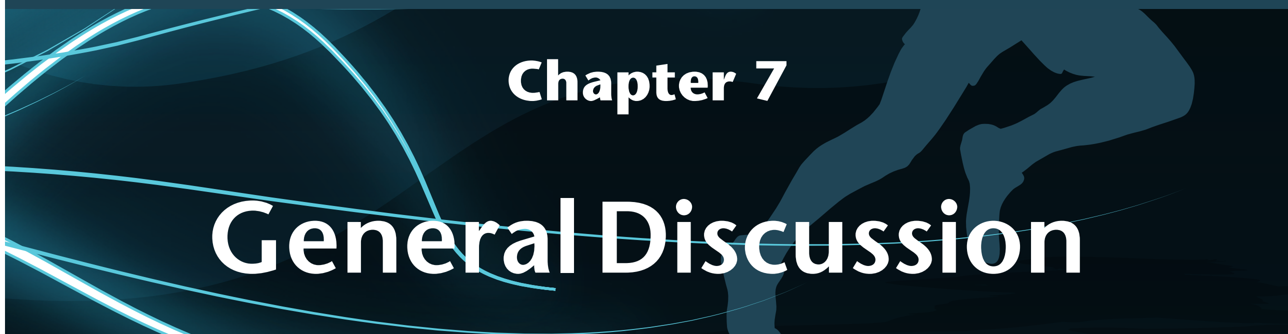

Chapter 7

General Discussion

General Discussion

In our systematic review [37], we found that previous injury, especially in men, and the use of orthotic/inserts appear to be risk factors for running-related injuries (RRIs), whereas we found little support for other frequently mentioned and potential risk factors for RRI. In our 3-month cohort study of female runners preparing for a 5- or 10-km running event (the Marikenloop), the only risk factors for RRI identified were weekly running distance (> 30 km) and previous running injury (> 12 months ago)[39]. Also, our studies[37, 38] showed that the RRI risk profiles of men and women are different. Moreover, although some of the findings in studies seemed to be contradictory, we did not find evidence that risk profiles are associated with the female anatomy, as frequently suggested in literature[39].

Furthermore, we found a high prevalence of gastrointestinal (GI) symptoms in our cross-sectional study of female runners preparing for a 5- or 10-km event[36]. Although several predictors (younger age, limited running experience, higher body mass index, consuming carbohydrate-containing drinks during running, and experiencing GI symptoms in general during running) were identified as contributing to the GI symptoms, more needs to be learned about the effects of pre-running eating and carbohydrate-containing drinks on GI symptoms during running.

In this section, we discuss our findings regarding follow-up time, exposure, and their interaction with reference to the dynamic reverse model of Meeuwisse[26]. A focus on foot strike, running shoes, and coordination in preventive strategies are discussed and suggestions for future research are given, with "take home messages" for the (starting) runner.

Dynamic recursive model

Running injuries have a multifactorial origin that can be divided into personal factors, running/training factors, and health and/or lifestyle factors [14, 23, 40]. These factors interact with each other and their influence may also be mediated by cultural or societal factors[4]. The importance of each factor, and hence its contribution to the risk of symptoms and injuries, varies among individuals and running environments[5]. The goal of the studies described in this thesis was to identify risk factors for RRI that can be used to develop injury prevention and/or screening strategies.

Several models describe how risk factors interact to increase the susceptibility to sports injury[2, 25, 41]. Although these models are based on sequentially occurring events[26], in running, exposure to a potential inciting event can alter a runner's intrinsic (personal) factors and change the predisposition to RRI. This means that a runner's susceptibility to injury is different on re-exposure to the same or different extrinsic (e.g. training, shoe, etc.) risk factors. Therefore, the risk of RRI may change continuously. Meeuwisse et al.[26] introduced a dynamic, recursive model of sport injury that can be used to gain an understanding of the etiology of running injuries, see figure 1.

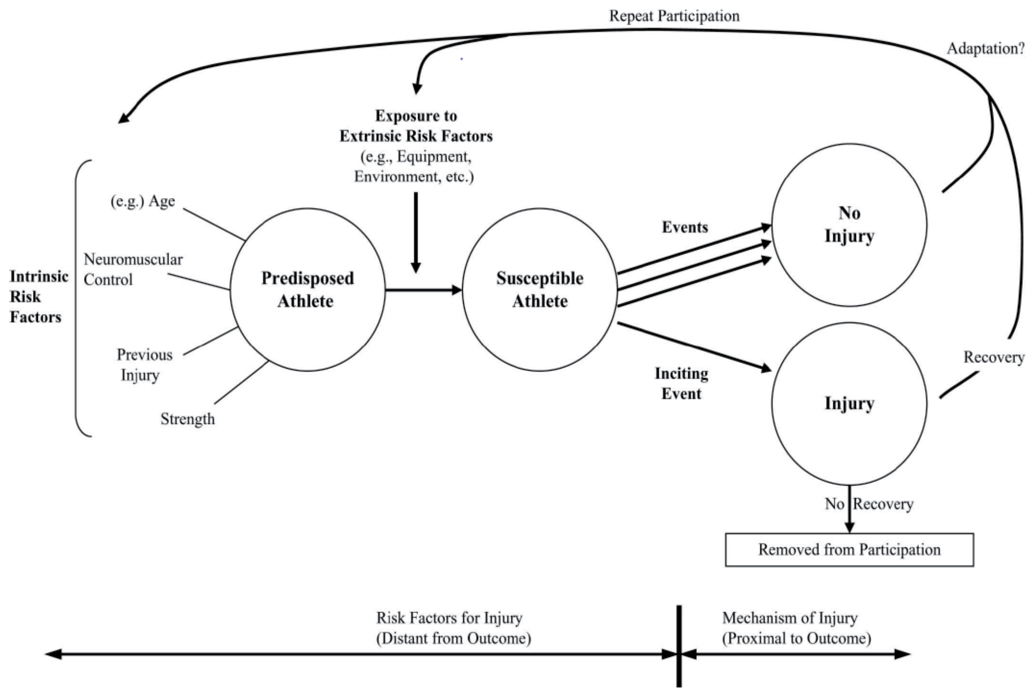

Figure 1: the dynamic recursive model of the etiology of running injuries (reproduced with permission[26])

Follow-up time

As in other studies investigating risk factors for RRI,[5, 13, 18] we assumed that risk factors would be stable over time during our prospective study of female runners taking part in the Marikenloop-run. Our study had a follow-up of 3 months and it seems reasonable to assume that intrinsic risk factors (e.g., age, BMI, navicular drop, etc.) would not change much during this period. However, overuse injuries in runners generally occur as result of exposure to repetitive forces, each below the acute threshold, but accumulation results in increasing fatigue over a long period of time leading to exceeding the capabilities of the specific structure[15]. Thus, a longer follow-up period might be more appropriate, if it is assumed that risk factors may change with a longer period of time and that the effect of fatigue is accumulative. Therefore, if the dynamic recursive approach is taken into account, intrinsic risk factors should be measured at regular intervals over a longer period of time to determine whether their influence on RRI risk fluctuates with time[26]. Moreover, attention should be paid to the choice of tools used to measure changes in independent variables over time. Such tools should have a high inter-test agreement, in order to be able to evaluate possible changes over time decreasing the influence of measurement error[10]. From this perspective, it can be questioned whether questionnaires are the best instrument to use, because they measure athletes' opinions, which may be susceptible to change under the influence of athletes' experiences.

In conclusion, the inability to detect consistent associations between risk factors and RRI in our and other studies may be because of a too short follow-up period and/or too infrequent assessments, which might be due to financial constraints. Future studies of RRI should have longer follow-up periods, use valid and reliable tools, and regularly measure intrinsic risk factors. The use of mobile apps is advised which made intensive monitoring easy in daily practice and research.

Furthermore, future studies should distinguish between different types of RRIs, such as chronic and overuse injuries and acute injuries. Whereas acute injuries are probably due to poor coordination and fatigue, overuse RRI may be characterized by an accumulative effect of disuse leading to fatigue over time. In a post hoc analysis of the data of our Marikenloop study, the risk factors investigated did not differ between female runners classified as having an acute RRI and those with an overuse RRI, but the risk factors investigated might not have been sensitive enough to differentiate between these groups of injured runners and/or the period of time was too short to identify overuse injuries. Therefore, studies investigating different types of RRI should take other relevant risk factors into account, as discussed below.

Running Exposure

We operationalized running exposure in the baseline questionnaire as weekly running distance in four categories (0–10 km, 10–20 km, 20–30 km, >30 km), with adjustment for possible confounders, such as running surface, running shoe age, etc. Although weekly running distance (> 30 km) was associated with RRIs, the variability in exposure, measured with the baseline questionnaire, probably meant that it was not valid to attempt to distinguish between runners with and without RRI on the basis of their exposure with a questionnaire. Although other studies used more precise and dynamic running measurements, such as weekly Internet training logbooks[5] and global positioning systems (GPSs),[29] to quantify exposure in terms of weekly running hours, even then it was not possible to consistently identify risk factors for RRIs[33, 37]. Although other studies have reported change in running exposure to be a key component in RRI[28, 30], so far it has not been possible to quantify exposure adequately to identify it as a specific risk factor for RRI. On the basis of the dynamic recursive model,[26] it might be necessary to measure exposure more often and more precisely and not only referring to time. Examples are in-shoe pressure-measurement systems that measure the location, magnitude, and temporal patterns of discreet plantar forces[34]. Combining these measurements with GPS information would provide more dynamic information about running exposure.

Biological Interaction

Although precise and frequent measurement of variables (e.g., exposure) is essential, the interaction between internal (e.g. mood, age, etc.) and external (e.g. shoe, trainings intensity, etc.) risk factors seems to be a key determinant of the occurrence of RRI.

In our cohort study,[39] variables were measured at baseline, but a more dynamic and interactive measurement of these variables might have been more appropriate. For example, simultaneous measurement of running exposure and potential (external and internal) risk factors might be the best approach to meeting the requirements of the dynamic recursive model of Meeuwisse[26] (see Figure 1). Also, as stated above, instruments should be valid and sensitive enough to detect minor changes over a short period of time[10].

In addition, personal risk factors, which may interact with other (potential) risk factors, should be included. Thus when increasing the frequency of variable assessment, it might be appropriate to also screen for psychosocial factors, because of their role in musculoskeletal disorders[7]. For example, mood, perceived tiredness, and external and internal expectations influence mental and physical performance and could be taken into account, together with running exposure, when investigating the occurrence of RRIs.

As we showed in our cross-sectional study,[36] there are several predictors of GI symptoms, and the prevalence of these symptoms is high. In a broader perspective, the eating and drinking patterns of runners may influence their performance and recovery from injury[31] and may interact with other potential risk factors for RRI. Therefore eating and drinking patterns should be included in the dynamic recursive model for the occurrence of RRIs.

In conclusion, future cohort studies focused on identifying risk factors for RRI should take into account the possible interaction between variables by intensifying the assessment frequency using valid and reliable tools. Furthermore, completing “the runner at risk” possible psychosocial, eating, and drinking risk factors for RRIs should be integrated in the model.

Foot strike

A person’s running technique has many components. The foot strike pattern in particular has a great influence on injury rates[8]. There are three categories of strike common to distance runners: 1) rearfoot strike (RFS), in which the heel contacts the ground first (heel–toe running) and is the pattern seen in 69% of runners[8]; 2) forefoot strike (FFS), in which the ball of the foot contacts the ground before the heel (toe–heel–toe running); and 3) midfoot strike (MFS), in which the heel and ball of the foot contact the ground simultaneously[8].

At initial contact with the ground, RFS runners have a relatively extended knee and relatively dorsiflexion position of the ankle, which are associated with relatively high impact forces[11, 22]. Impact transients associated with RFS running are sudden forces with high rates and magnitudes of loading that travel rapidly up the body and thus may contribute to the high incidence of RRIs[16]. Our finding that heavier women had a higher risk of RRI[39] could be explained in terms of extra high impact forces with higher rates and magnitude of loading on the extremities[27].

Runners with MFS or FFS patterns, associated with barefoot-, Chi- and Pose-running, have a relatively increased foot and ankle plantar flexion and increased knee flexion at ground contact[11]. This type of runner has a decreased stride length and greater leg and ankle compliance combined with a quicker turnover rate to lower the body’s center of mass relative to the force of impact, causing the foot to land more vertically aligned with the hip and knee[1, 11, 16]. Increased plantar flexion of the foot at landing and greater ankle compliance during impact, decrease the effective mass of the body that collides with the ground, thereby significantly decreasing the average loading rate[22].

Therefore, in the case of specific RRIs based on impact forces (e.g., tibial stress fractures[43]), average loading rates (e.g., patellofemoral pain syndrome6), and/or reduced arch strength (e.g., plantar fasciitis[22]), it seems useful to modify the runner’s foot-strike technique from RFS to MFS or FFS[12] in order to prevent RRIs [1, 6, 11, 12, 16.] Although recent reviews of barefoot running[1, 12, 16] and various associated running styles (Chi and Pose running)[11] concluded that there are positive effects of a forefoot strike pattern, advice about running style should be given with caution because of the low quality of studies and the short-term effect[12]. Future studies should confirm whether MFS and/or FFS prevent RRIs or whether these running styles are associated with other types of RRIs[11]. Until then, caution is appropriate when advising preventive changes in running style in individual runners.

Furthermore, as stated above, ankle mobility is an important component of the type of foot strike. Although, in our post hoc analysis we did not find dorsiflexion of the ankle to be a risk factor for RRIs in our cohort study[39], we should perhaps have taken into account the mobility of the plantar flexion of this joint as a factor for RRI and made subgroup analysis for the different types of foot strike. Therefore, future cohort studies should assess the total mobility of the ankle, inclusive plantar flexion of the ankle, in large groups of runners with different foot strike patterns, to determine whether ankle joint mobility is a determinant of RRIs.

Running shoe & coordination

Most traditionally shod runners have a RFS due to the additional cushioning that cushioned shoes provide[21]. The cushioned heel of footwear positions the sole of the foot in 5° less dorsiflexion than the sole of the shoe, thereby permitting runners to have a RFS more often and with greater comfort. A negative point is that these shoes limit proprioception of the foot[16, 22]. Furthermore, many running shoes have arch supports and stiffened soles that may lead to weaker foot muscles, reducing arch strength[22, 24]. This weakness contributes to excessive pronation and places greater demands on the plantar fascia, which may cause plantar fasciitis[22].

From a mechanical point of view, a disadvantage of footwear is that its geometry elevates the position of the foot and increases the lever arm length between the ground reaction force and the subtalar joint axis[16]. This altered position decreases ankle coordination and magnifies supination forces and stresses on the lateral ankle ligaments during running[35]. Therefore a larger muscle contraction is needed, reflecting a larger compensatory mechanism, to counteract the inherent inversion of the shod condition[16] In our cohort study[39], the type and history of the running shoe (shoe age and the distance of the running shoe) was not associated with RRI. Therefore, it is possible that the running shoe itself is not the problem, but rather the type of running shoe: traditional running shoe vs. barefoot or minimal running shoe. This is in agreement with the literature. The study of Kurz and Stergiou[20] found that the ankle adopts new coordinative strategies when a runner runs barefoot versus with shoes. They suggested that coordinative strategies might be related to different mechanisms by which impact forces are attenuated during running. Also, a significantly larger variability in the joint pattern was found in barefoot runners than in shod runners, so by varying the joint pattern, forces are spread across various tissues to prevent overuse injuries[19].

In conclusion, runners continually modify their ankle and foot position to optimize efficiency and to avoid an undesirable foot position, based on sensory feedback to the limb, aspects which seem to be optimized when running barefoot or with minimal running shoe[9, 16]. However, changing a person's running style places greater demands on the foot and ankle, as stated above, and (transition) injuries of the foot and lower leg have been reported[1, 16]. Therefore, the running technique should be changed slowly, to allow proper adaptation[9]. No studies have investigated the most effective implementation program[16]; however, foot exercises or a combination of foot exercises with a conservatively designed transition running program would seem to be appropriate[9]. The "foot core" should be optimized by performing foot-doming exercises,[17, 24] and a transition running program, as proposed by Warden et al., is advised[9].

Research is needed to determine the best way to change the running style safely in order to reduce the incidence of injuries during the transition period. Furthermore, research is needed to establish which individuals with certain morphological or mechanical gait characteristics may benefit from alternative running styles that incorporate a more barefoot (MFS or FFS) running style[9, 11]. The relative importance of potential risk factors measured in our cohort study, e.g., extension of the metatarsophalangeal 1 joint, varies depending on the choice of running shoe or foot strike pattern of the runner. These risk factors, adjusted for running style, should be taken into account in future studies and, as suggested above, the use of with in-shoe pressure-measurement systems that measure the location, magnitude, and temporal patterns of discreet plantar forces[34] seems most ideal to measure the mechanical gait characteristics.

Previous research on proprioception, neuromuscular adaptation, and exercise[3, 32] should be extended to make it more running (injury) specific. For example, the possibility of fatigue-related proprioceptive errors and an altered body scheme when there is a decrease in muscle force after intensive eccentric exercise, such as running[32]. This knowledge may change our perspective from a biomechanical perspective to a more neuromuscular perspective, which may affect running training programs in terms of exposure in combination with coordination and/or economy[3, 16, 32.] Again, the recurrence model of Meeuwisse et al.[26] would seem to be essential.

Conclusion

Our and other investigators' failure to consistently identify risk factors for RRIs may mean that there is no generic risk profile for these injuries and injuries are the result of an accidental coincidence of internal and external factors. However, before this conclusion can be established, larger prospective studies are necessary with a longer follow-up and more emphasis on the interactions between potential risk factors for RRI, with the dynamic recursive model being used as theoretical basis.

Fundamental (laboratory) studies investigating theoretical models on cause and effect of external load, especially in relation to proprioceptive changes, neuromuscular adaptation, and exercise on RRIs are needed, and the possible difference in acute and overload RRIs should be investigated. When these mechanisms are understood longitudinal prospective studies or even randomized experiments are the next step. Given the small number of studies that investigated the effect of runner's sex on RRIs, it was not possible to establish sex-specific profiles for risk factors. Emphasis should be placed on research involving female runners because they have been under-represented, relative to male runners, in studies to date.

Lastly, it is important that people who (want to) start running realize that the statement "to start with running, just a pair of running shoes is needed" might be too simple – good guidance, by an experienced running trainer and or specialist (e.g., sports physician, sports physical therapist), especially with regard to the individual's personal running style, is essential in order to maintain the health benefits of running and to prevent RRIs. It is important that runners, and especially their supervisors, realize that RRIs are a consequence of trainings errors involving a change (increase) in the frequency, pace, or distance run, or a combination of these factors[30]. Therefore, monitoring the runners training activity seems to be essential and nowadays easy to establish with GPS-devices in combinations with mobile apps. Previous injury remains the most import risk factor for RRIs and therefore running analysis, personalized training schedules, advice, and preventive exercises are essential to prevent RRI and to sustain the health benefits of running.

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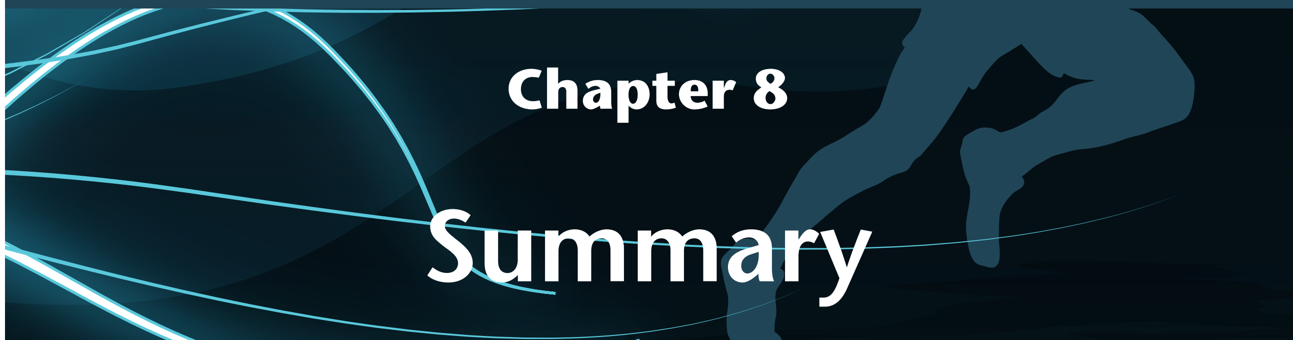


Chapter 8

Summary

Summary

Running is very popular worldwide and has a positive effect on general health and wellbeing. Furthermore, this aerobic sport is effective in both curative and preventive settings. However, the rate of running-related injuries (RRIs) and associated costs are high, especially for knee injuries. There are a number of risk factors for RRIs, and there is some evidence that the risk profile of female and male runners may be different, but this has not yet been established firmly. Female runners are particularly interesting because running is still a growth sport among women, and a better knowledge of risk factors for RRIs in female runners would enable targeted prevention strategies.

In order to facilitate the evidence-based management of iliotibial band syndrome (ITBS) in runners, more needs to be learned about the etiology, diagnosis, and treatment of this injury. **Chapter 2** describes a systematic literature review that investigated the quality of the scientific knowledge about the management of ITBS. Different databases and reference lists were searched, using specified selection criteria. Two reviewers independently screened the search results, assessed methodological quality, and extracted data. The results of this systematic review showed that studies of the etiology of ITBS in runners have provided limited or conflicting evidence, and it is not clear whether the hypothesized hip abductor weakness plays a major role in the etiology of ITBS. The review also revealed that the kinetics and kinematics of the hip, knee, and/or ankle/foot are different in runners with or without ITBS. The biomechanical studies involved small samples, and data seem to have been influenced by the sex, height, and weight of the participants. In most studies, the rehab management of ITBS was monitored with clinical tests, but these tests have not been validated for this patient group. While different treatments were used for ITBS, hip/knee coordination and running style appeared to be key
factors in the treatment of ITBS. Runners might also benefit from mobilization, exercises to strengthen the hip, and advice about running shoes and running surface. On the basis of our findings, we concluded that the methodological quality of research into the rehab management of ITBS in runners is poor and that study designs should be improved to prevent selection bias and to increase the generalizability of findings.

The review described in **Chapter 3** investigated risk factors for RRIs in adults and whether these factors are different in men and women. The databases PubMed, EMBASE, CINAHL, and Psych-INFO were searched for longitudinal cohort studies with a minimal follow-up of one month that investigated the association between risk factors and the occurrence of lower limb injuries in runners. Two reviewers' independently selected relevant articles from those identified by the systematic search and assessed the risk of bias of the included studies. The strength of the evidence was determined using a best-evidence rating system, and sex differences in risk were determined by calculating the sex ratio for risk factors (the risk factor for women divided by the risk factor for men). This systematic review showed that,

overall, women are at lower risk of sustaining RRIs than men. Furthermore, strong and moderate evidence was found that a history of previous injury and of having used orthotics/inserts respectively is associated with an increased risk of RRIs. There appeared to be differences in the risk profile of men and women, but as few studies presented data for men and women separately, the results should be interpreted with caution. The study highlighted the need to minimize methodological bias by paying attention to recall bias for running injuries, follow-up time, and the participation rate of the identified target group.

The aim of the clinimetric study reported in **Chapter 4** was to determine the reproducibility of three orthopedic tests; 1) the navicular drop-test (NDT), 2) the ankle joint dorsiflexion-test (AJD-test), and 3) the test of the extension of the metatarsophalangeal joint 1 (MTP1-test), and whether there are sex differences in test results. These tests are often used in daily running practice, and because they require minimal equipment, they are suitable for large cohort studies as well. The three orthopedic tests were administered by two sports physical therapists to 22 male (39.1 yrs ± 14.7) and 20 female (37.2 yrs.± 9.3) recreational runners. The reproducibility of the AJD test was found to be good, whereas that of the NDT and extension MTP1 was moderate or low. There was a difference between male and female runners in mobility in the NDT and MTP1, but this need to be investigated further in a larger study with more reliable test procedures.

The study described in **Chapter 5** involved participants in the Marikenloop 2013. The purpose of this 3-month prospective cohort study of female recreational runners was to determine, using questionnaires and orthopedic tests, the occurrence of RRIs and whether the occurrence of injuries is affected by personal, anthropometric, running and running shoe characteristics, a history of running RRIs, and degree of foot pronation and extension of the metatarsophalangeal I joint, with a view to develop injury prevention strategies. The Marikenloop run over 5 or 10 km is for women only and thus provides a unique opportunity to rectify the deficit in research into female runners participating in running events. Of 13,500 women registered for the 5- or 10-km Marikenloop run, 417 participated in this study.
We found that the incidence of RRIs was similar in 5- and 10-km runners, with only two risk factors (weekly running distance and previous RRI) being found to be associated with RRI in female runners preparing for the race. Thus strategies focusing on these two risk factors may have a role in RRI prevention. However, more prospective research, with a large group of runners and detailed description of running exposure, is needed to confirm our findings, especially among female event runners.

Another downside of running, in addition to the injuries, is the complaints of gastrointestinal (GI) symptoms. In the study reported in **Chapter 6**, we investigated the prevalence of GI symptoms in women during the 5- or 10-km Marikenloop run in general, and the association between nutritional intake and GI symptoms. A cross-sectional questionnaire was distributed among interested runners participating in the Marikenloop study. The primary outcome was the frequency of GI symptoms during running in general and during the last training run. Dietary intake was determined before and during this run. Secondary outcomes were several demographic and anthropometric variables.
The questionnaire was completed by 433 female runners. During running in general, 40% of the participants had GI symptoms, and during their last run, 49%. The GI symptoms reported most often were side ache, flatulence, urge to defecate, and regurgitation and/or belching. Younger age, limited running experience, higher body mass index, consuming carbohydrate-containing drinks during running, and experiencing GI symptoms during running in general significantly contributed to GI symptoms during the last training run. In contrast, time of eating the last meal and drinking carbohydrate-containing drinks before the run were not associated with GI symptoms. This study thus confirmed the high prevalence of GI symptoms in female runners. Several predictor variables contributed to the GI symptoms, but more research is required to specify the effects of pre-running consumption of food and carbohydrate-containing drinks on GI symptoms during running.

In the general discussion presented in **Chapter 7**, we discussed the findings of our studies concerning follow-up time, exposure, and interaction in terms of the dynamic reverse model. Foot strike, running shoe, and coordination are presented as possible key targets for preventive strategies, with practical applications for runners and sports medicine.
We concluded that, given the apparently random nature of our findings and those of other investigators regarding the identity of risk factors for RRIs, there may not be a generic risk profile for RRI. However, this should be substantiated in larger prospective studies with longer follow-ups and more emphasis on the interactions between potential risk factors for RRI. The dynamic recursive model could function as theoretical basis in these studies.
Laboratory studies are needed to test the value of theoretical models regarding the cause and effect of RRIs, with emphasis on proprioception, neuromuscular adaptation, and exercise. Furthermore, it needs to be established whether there are differences between acute and overload RRIs. Only when these mechanisms of cause and effect are understood, longitudinal prospective studies can be useful to observe changes over time.

We concluded that, in daily practice, it is important that people who want to start running should realize that the statement “to start with running, just a pair of running shoes is needed” is rather simplistic or optimistic – it is essential that ‘new’ runners receive guidance, by an experienced running trainer and/or specialist (e.g. sports physician, sports physical therapist), on how to build up their running program, with a focus on personal running style, in order to sustain the health benefits of running and to prevent RRIs.

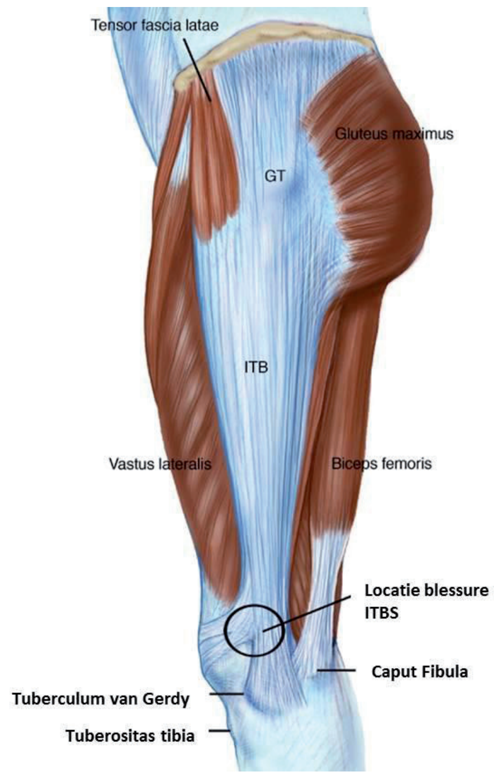
Runners, and also their supervisors, need to appreciate that RRIs are a consequence of training errors, such as a too rapid increase in pace, distance, or both. Therefore, monitoring the runners training activity seems to be essential and nowadays easy to establish with GPS-devices in combinations with mobile apps. Previous injury is the most import risk factor for RRIs established to date and therefore analysis of the runner’s running style, personalized training schedules, advice, and preventive exercise are essential to ensure that running remains a form of exercise.

Chapter 9

Samenvatting

Samenvatting

Hardlopen is wereldwijd een populaire sport en heeft een positief effect op de algehele gezondheid en welzijn. Het nadeel van hardlopen is de grote kans op het krijgen van een blessure en de hoge kosten, die daar een gevolg van zijn.
Verder lijkt er een verschil te bestaan tussen mannen en vrouwen in het risico voor het krijgen van hardloopblessures, maar het risicoprofiel van beide geslachten is nog niet duidelijk. Het helder krijgen van het risicoprofiel voor hardloopblessures is vooral interessant voor vrouwen daar deze groep hardlopers nog steeds groeiende is en meer kennis van de risicofactoren kan worden gebruikt voor het inzetten van preventieve interventies.



Figuur 1: Laterale zijde bovenbeen met de locatie van de ITBS blessure. ITB; iliotibiale band, GT; trochantor major (gekopieerd/vertaald met toestemming, Baker et al., 2011)

De meeste hardloopblessures treden op in de knie. Er wordt een incidentie beschreven van 7% tot 50%. De meeste voorkomende blessure aan de buitenkant van de knie bij hardlopers is het Iliotibiale Band Syndroom; zie figuur 1.
Om de revalidatie van lopers met het Iliotibiale Band Syndroom (ITBS) te optimaliseren is er meer inzicht en evidentie nodig ten aanzien van de etiologie, diagnose en behandeling van dit syndroom.

Hoofdstuk 2 beschrijft een systematische review die de kwaliteit beoordeelt van de wetenschappelijke literatuur ten aanzien van het management van het Iliotibiale Band Syndroom (ITBS). Verschillende databases en referentielijsten werden bekeken om de relevante literatuur te bestuderen. Twee onafhankelijke onderzoekers screenden de artikelen, beoordeelden de geïncludeerde literatuur op de methodologische kwaliteit en deden de data extractie. De resultaten van deze systematische review lieten zien dat de studies ten aanzien van de etiologie van ITBS beperkte of tegenstrijdige resultaten presenteren. Het is onduidelijk welke rol een vermindering van de heupabductiekracht speelt. Verder komt naar voren dat de kinematica en kinetica van heup, knie en enkel/voet verschilt tussen hardlopers met en zonder ITBS. De geïncludeerde biomechanische studies bevatten kleine groepen en de resultaten lijken te worden beïnvloed door geslacht, lengte en gewicht. Daarnaast werd duidelijk dat de geïncludeerde studies gebruik maakten van testen en meetinstrumenten die niet klinimetrisch onderzocht zijn voor deze groep hardlopers. Hoewel de geïncludeerde studies inconsistent waren ten aanzien van de behandeling van ITBS lijken de heup- en kniecoördinatie en de hardlooptechniek bepalende elementen te zijn in de behandeling van ITBS. Hardlopers met ITBS lijken ook baat te hebben bij mobilisatie en spierversterkende oefeningen voor de spieren van de heup en advies ten aanzien van hardloopschoenen en ondergrond (asfalt, zand, etc.). Tot slot werd er aan de hand van onze bevindingen geconcludeerd dat de methodologische kwaliteit van het onderzoek naar ITBS bij hardlopers zeer matig is. Vervolg studies zouden meer gebruik moeten maken van longitudinaal prospectieve studiedesigns zodat selectiebias voorkomen kan worden en het de generaliseerbaarheid van de gegevens vergroot.

Hoofdstuk 3 beschrijft in de vorm van een systematische review het onderzoek naar de risicofactoren van hardloopblessures en het mogelijke verschil tussen mannen en vrouwen in deze. In de volgende databases, PubMed, EMBASE, CINAHL en Psych-INFO, werd gezocht naar longitudinale cohortstudies met een minimale follow-up van 1 maand en naar studies welke de relatie onderzochten tussen risicofactoren en het ontstaan van blessures van hardlopers. Twee onafhankelijke reviewers selecteerde de relevante artikelen en bepaalden de methodologische kwaliteit van de geïncludeerde studies. De mate van bewijskracht werd bepaald middels een best-evidence rating systeem en het risicoverschil tussen mannen en vrouwen werd bepaald middels de geslachtsverhouding (het risico voor het krijgen van een hardloopblessure voor vrouwen gedeeld door dit risico voor mannen). De resultaten van deze systematische review laten zien dat vrouwen een lager risico hebben op het ontstaan van hardloopgerelateerde blessures dan mannen. Verder werd er sterke en gemiddelde aanwijzing/evidentie gevonden dat een eerdere blessure en schoenorthese/zooltjes waren gerelateerd aan een verhoogd risico op het krijgen van hardloop blessures. Tevens werd er een verschil in risico gevonden tussen mannen en vrouwen, maar doordat weinig studies de resultaten van mannen en vrouwen apart vermelden moeten deze resultaten voorzichtig geïnterpreteerd worden. Vervolgonderzoek zal vooral gericht moeten zijn op het minimaliseren van bias door aandacht te besteden aan recall bias voor hardloop blessures, het optimaliseren van de follow-up tijd en het aantal hardlopers met blessures in de desbetreffende onderzoeken.

De klinimetrische studie, beschreven in **hoofdstuk 4**, had als doel de reproduceerbaarheid van drie orthopedische testen te bepalen: 1) de naviculaire droptest (NDT), 2) de enkeldorsaalflexietest (EDT) en de test voor de extensie van het metatarsophalangeale gewricht 1 (MTP1-test). Deze testen worden in de dagelijkse praktijk vaak bij hardlopers gebruikt en door een protocol te hanteren met minimale apparatuur en korte uitvoeringstijd zijn deze testen praktisch goed bruikbaar voor grote cohort studies. Verder had deze studie tot doel het man-vrouw verschil van de uitslagen van deze testen vast te stellen.
De drie orthopedische testen werden in een fysiotherapiepraktijk uitgevoerd door twee ervaren sportfysiotherapeuten bij 42 recreatieve hardlopers; 22 mannen met een gemiddelde leeftijd van 39.1 jaar (sd: 14.7) en 20 vrouwen met een gemiddelde leeftijd van 37.2 jaar (sd: 9.3). De resultaten laten zien dat de reproduceerbaarheid van de EDT goed is, maar van de NDT en MTP1-test gemiddeld tot laag is. De uitslagen van de NDT en MTP1-test waren verschillend tussen mannen en vrouwen. Dit verschil zal verder moeten worden onderzocht in grotere studies met betere reproduceerbare testprotocollen.

In **hoofdstuk 5** worden de resultaten beschreven van een prospectieve cohortstudie met een follow-up van drie maanden bij deelneemsters aan de Marikenloop in Nijmegen. Het doel van deze studie was het bepalen van de incidentie, de locatie en de risicofactoren van hardloopgerelateerde blessures bij vrouwen die zich voorbereidden op de Marikenloop van 2013. Van de 13.500 vrouwen die zich hadden ingeschreven aan deze Marikenloop participeerde 417 in deze studie. De 3 maanden incidentie voor het krijgen van een hardloop gerelateerde blessures was 26.1% en verschilde niet tussen de hardloopsters van de 5 km en 10 km. De meest voorkomende blessures waren gelokaliseerd aan de knie en het onderbeen. De mulitivariabele Cox regressieanalyse toonden aan dat de wekelijkse hardloopafstand (>30 km p/w) en een eerdere hardloopblessure (> 12 maanden geleden) geassocieerd zijn met het krijgen van een hardloopblessure. Met deze studie toonden we aan dat preventieve maatregelen zullen moeten worden ingezet ten aanzien van wekelijkse hardloopafstand en een eerder doorgemaakte hardloopblessure. Wel is meer prospectief longitudinaal onderzoek nodig waarbij de mate van hardloopbelasting (duur, frequentie en snelheid) nauwkeurig gekwantificeerd wordt.

Een andere keerzijde van hardlopen, naast het blessureleed, zijn maag en darm klachten. **Hoofdstuk 6** beschrijft de studie die als doel had de prevalentie van maagdarm klachten vast te stellen van vrouwen die deelname aan de 5 of 10 km van de Marikenloop 2013 en de relatie aan te tonen tussen voedselinname en maagdarm

klachten tijdens en na het hardlopen.
Er werd een vragenlijst afgenomen bij de geïnteresseerde hardloopsters van de Marikenloop studie (zie hoofdstuk 5). De primaire uitkomstmaat was de frequentie van maagdarmklachten tijdens het hardlopen (algemeen) en specifiek tijdens de laatste (trainings)loop. Daarnaast werd de voedselinname bepaald van voor en tijdens deze laatste (trainings)loop. Secundaire uitkomstmaten waren demografische en antropometrische variabelen.
De vragenlijst werd door 433 vrouwen ingevuld. Veertig procent van de deelnemers had last van maagdarmklachten tijdens het lopen en 49% tijdens de laatste (trainings)loop. De maagdarmklachten die het meest werden gerapporteerd waren steken in de zij, winderigheid, aandrang tot ontlasting en oprisping en/of boeren. Uit de logistische regressieanalyse bleek dat een lagere leeftijd, weinig hardloopervaring, hogere Body Mass Index, gebruik van koolhydraatrijke dranken tijdens het hardlopen en het ervaren van maagdarmklachten tijdens het hardlopen in het algemeen significant bijdragen tot het krijgen van maagdarm klachten tijdens de laatste (trainings)loop. Het tijdstip van eten en koolhydraatrijke dranken voor het hardlopen waren niet gerelateerd aan maagdarm klachten.
Concluderend kan men zeggen dat er een hoge prevalentie is van maagdarmklachten bij vrouwelijke hardlopers en dat er verschillende voorspellende factoren zijn voor het krijgen van maagdarm klachten, maar ook dat er meer onderzoek nodig is om de specifieke effecten van eten en drinken op het ontstaan van maagdarm klachten tijdens het hardlopen te kunnen bepalen.

Hoofdstuk 7; de algemene discussie. In deze discussie worden de uiteenlopende bevindingen van onze en andere studies, aan de hand van het "dynamic recursive" model, besproken. Dit model beschrijft terugkerende (risico)factoren die mede kunnen leiden tot het ontstaan van hardloopblessures.
Aandachtspunten die worden besproken zijn de follow-up tijd, de hardloopbelasting en de interactie tussen verschillende variabelen. Daarnaast ligt de nadruk in deze discussie op voetafwikkeling, hardloopschoen en coördinatie van het hardlopen als mogelijke belangrijke factoren ten aanzien van preventieve strategieën bij hardloopgerelateerde blessures. Deze discussie wordt afgesloten met praktische adviezen en tips voor hardlopers en (para-)medici.
Als eerste wordt geconcludeerd dat er mogelijk geen algemeen risicoprofiel is voor het ontstaan van hardloopblessures. Voordat deze conclusie echt gestaafd kan worden zullen er grotere prospectieve studies nodig zijn met een langere follow-up tijd en meer nadruk op de interacties tussen de verschillende risicofactoren van hardloopblessures, waarbij het "dynamic recursive" model als theoretisch basis goed zou kunnen fungeren. Tevens concluderen we dat er eerst meer fundamenteel (laboratorium) onderzoek zal moeten worden gedaan naar de theoretische modellen ten aanzien van oorzaak-gevolg relatie van hardloopblessures. De nadruk zal hierbij moeten liggen op de relatie tussen externe belasting en de propriocepsis, neuromusculaire adaptatie en training in relatie tot acute of overbelastingsblessures.

Wanneer de mechanismen van oorzaak en gevolg duidelijk zijn, lijken longitudinale prospectieve studies zinvol.
Verder valt op dat er nog weinig studies zijn die apart hebben gekeken naar het risico van hardloopblessures bij mannen en vrouwen, hierdoor was het niet mogelijk om per geslacht een specifiek risicoprofiel op te stellen. Vervolgonderzoek zal dus meer nadruk moeten leggen op het vergelijken van de uitkomsten voor zowel mannen als voor vrouwen zodat geslacht specifieke evidence based risicoprofielen indien aanwezig gewaarborgd kunnen worden. De nadruk zal hierbij moeten liggen op onderzoek bij vrouwen, daar er aanzienlijk minder onderzoek bij vrouwen is gedaan.
Als laatste geven we advies voor de dagelijkse sportpraktijk. Het is belangrijk dat mensen die willen gaan hardlopen zich realiseren dat het statement "beginnen met hardlopen, het enige wat je nodig hebt is een paar hardloopschoenen" veel te optimistisch is. Een goede begeleiding door een ervaren hardlooptrainer of hardloopspecialist (sportarts, sportfysiotherapeut, etc.) is belangrijk, waarbij de trainingsopbouw en hardlooptechniek essentieel zijn om de positieve gezondheidseffecten van hardlopen te optimaliseren en hardloopblessures te voorkomen. Verder benadrukken we dat hardlopers, maar ook hun directe begeleiders, zich moeten realiseren dat hardloopblessures primair worden veroorzaakt door fouten in de trainingsopbouw; te snel, te veel en/of te lang. Daarnaast blijkt een eerdere (hardloopgerelateerde) blessure de meest belangrijke risicofactor te zijn voor het krijgen van een hardloopblessure. Dus zijn een persoonlijk afgestemd trainingsschema (goed gemonitord met de hulp van bijvoorbeeld GPS-apparatuur en mobiele-apps), met gerichte individuele adviezen en preventieve oefeningen (bijvoorbeeld excentrisch trainen van de heupabductoren) essentieel om vrij van blessures te kunnen blijven genieten van het hardlopen.

Dankwoord

Dankwoord

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Curriculum Vitae

Curriculum Vitae

Maarten van der Worp werd geboren op 10 november 1969 in Woudenberg. Na zijn middelbare school (mavo en havo) aan de Openbare scholengemeenschap 'De Amersfoortseberg' in Amersfoort is hij in 1988 begonnen aan de opleiding Fysiotherapie aan de Hogeschool Utrecht. In 1992 heeft hij deze studie afgerond. Vervolgens is Maarten begonnen met zijn master Bewegingswetenschappen (BW) aan de Vrije Universiteit van Amsterdam met als hoofdrichting inspanningsfysiologie en nevenrichting sportpsychologie. In 1997 studeerde Maarten, met een aantekening "lesbevoegdheid" (Docenten Opleiding), af aan de faculteit BW. Tijdens zijn studies Fysiotherapie en BW volgde hij verschillende cursussen wat in 1994 leidde tot het diploma sportfysiotherapeut. Tevens deed Maarten zijn Master Manuele therapie (2003-2006) aan de Vrije Universiteit van Brussel in België.

Maarten is na zijn opleiding tot fysiotherapeut werkzaam geweest op verschillende werkplekken als sportfysio- en manueeltherapeut. Hij begon met een eigen praktijk voor fysiotherapie in Amersfoort, vervolgens heeft hij gewerkt in een particuliere praktijk in Wuppertal (Duitsland) en op de afdeling cardiologie van het toenmalige Academisch Ziekenhuis te Rotterdam. Hij vervolgde zijn loopbaan bij Fysiotherapeuten Maatschap Woerden, waar hij met veel plezier samenwerkte met maatschapslid en sportfysiotherapeut Hajo van den Berg op de vestiging Snel & Polanen in Woerden. In 2002 maakte hij zijn laatste carrière switch en sindsdien werkt Maarten bij de Stichting Academie Instituut voor Fysiotherapie+. Samen met zijn collega's Holger Drechsler en Nick van de Horst is hij actief binnen het Been Expertise Centrum (BEC) en heeft Maarten zich met name gericht op het voorkomen en behandelen van hardloopblessures; Hardloopblessurevrij.nl

Gedurende de opleiding BW ontmoette hij zijn vrouw Petra Habets. Petra en Maarten hebben samen drie kinderen Lotte (2004), Pim (2006) en Niels (2008) en wonen in Werkhoven.

In 2010 is Maarten begonnen met het schrijven van zijn eerste artikel over de "hardlopersknie" en werd hierbij begeleid door dr. Anton de Wijer, Prof. Dr. Frank Backx en later ook Prof. Dr. Ria Nijhuis- van der Sanden. Prof. Dr. Ria Nijhuis- van der Sanden zorgde, samen met Dr. Bart Staal, voor een promotie plek bij IQ-Healthcare van het Radboud universitair medisch centrum te Nijmegen in samenwerking met het lectoraat Musculoskeletale Revalidatie van de Hogeschool Arnhem en Nijmegen.

Maarten kreeg het hardlopen met de paplepel ingegoten. In zijn jonge jaren was het vrijdagmiddag rondje "kaasboerderij" hardlopen, samen met zijn vader, standaard. De eerste jaren liep de vader van Maarten voorop, waarbij Maarten braaf volgde en duidelijk moest aangeven wanneer het te hard ging! Inmiddels zijn de rollen gelukkig omgedraaid en doen ze het inlopen nog samen, waarna Maarten al snel het groene licht krijgt: "ga maar vast...."